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TRANSLATED FROM THE GERMAN,

BY WM. BALY, M.D.

GRADUATE IN MEDICINE OF THE UNIVERSITY OF BERLIN.

ARRANGED FROM THE SECOND LONDON EDITION,

BY JOHN BELL, M.D.

LECTURER ON MATERIA MEDICA AND THERAPEUTICS, AND FORMERLY ON THE INSTITUTES OF MEDICINE AND MEDICAL JURISPRUDENCE, &c.

PHILADELPHIA:
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PREFACE.

He who engages in the labour of abridgement ought to feel that it is a self-imposed task, for the successful performance even of which he will not always be requited by the gratitude of those for whose benefit it was undertaken. It is not enough that he is faithful to his original, and that, while preserving its continuity of narrative and description, he retains all that is relevant in facts and valuable in doctrines; thus giving, in reduced dimensions, the characteristic features which were spread out with fatiguing amplification in the large work. Expectation will still go beyond ability; and, after all his conscientious pains-taking, he must be prepared to hear of omissions charitably imputed to him as negligences, and of compression complained of as obscurity. Many who never read the original, and who would have been repelled by its length and perplexing details, some who knew nothing at all antecedently of its character, will affect a sudden critical illumination, and with an oracular shrug whisper a wish that it had been spread out before them entire.

If from timidity, or want of entire conviction of the propriety of undertaking to abridge Müller's great work on Physiology, it were deemed necessary to invoke the sanction of authority, the editor of the present volume might refer to one eminent teacher,* who advised the measure, and to another† who gave it his ready approval. The editor, himself, felt assured, from an experience of many years teaching Physiology, as part of and in connection with the Institutes of Medicine, that the work of Müller in its entireness, however admirably calculated it may be to furnish information to the writer and lecturer, is not adapted to the wants, nor can it come within the requirements of the student of medicine. It is a vast repertory of facts and opinions in physiological science, but it bewilders the inexperienced votary by its very extent; and he who has gone over it without halt or pause, or, indeed, at all, may well speak, as even the indefatigable German student himself is said to do, of his having performed a feat.

---

* Dr. Horner.

† Dr. Jackson.

In arranging the volume now offered to American readers, from the materials furnished in *Müller's Elements of Physiology*, the editor has endeavoured to procure reduction in size of this latter, without any abstraction of its vitality and mind. With this view he has omitted, for the most part, mere disquisitions, many details of experiments, matters of physics and natural philosophy, including mechanics under the head of locomotion, acoustics and the theories of music under voice and hearing, and of optics under vision,—much of the minutiæ of comparative physiology, and metaphysics or metaphysico-physiology. But, while excluding details on collateral topics, the editor has been particularly careful to preserve physiology proper, which, resting on the basis of histogeny and general anatomy, derives important aid from organic chemistry and microscopical observations, and, in its turn, serves to illustrate hygiene, pathology and therapeutics. Thus aided and thus applied, in the manner exhibited by Müller himself, physiology will invite the attention of the student in these pages.

It will soon be discovered that, although this volume is an abridgement of the large work of Müller, it may rightfully claim to be considered a complete system of physiology, exceeding in copiousness and comprehensive details, any other work on the same subject, which has yet emanated from the London press.

Ample apology for the exclusion of topics merely collateral, which are taught and explained in separate and appropriate works, is furnished by the author himself, as indeed by other physiologists of distinction, in his purposely omitting to describe the details of the structure of each organ. He very properly refers the student for these matters to books of special anatomy. With still greater propriety should a similar reference be made when questions on the theories of light and colours, and of acoustics, &c. are under notice. If a moderate acquaintance with chemistry is supposed to be possessed by the student of Physiology, ought we not *à fortiori* to presume that he is not ignorant of, or at least can soon acquire, a sufficient knowledge of optics, acoustics and mechanics, to follow his author and to understand the allusions to various points included in these branches of science?

The reduction has not been after a uniform scale or rule of definite proportion. In some parts of the 'Elements,' comparatively little abbreviation has been attempted;—as in the prolegomena of general physiology, which is a carefully condensed summary of the subjects embraced under the general head, and does not admit, without obscurity, of any material curtailment. So, likewise, in the case of the functions of organic life, those of assimilation, nutrition and decomposition, much of the copiousness of facts and illustrations which constitutes so distinguishing a merit in the larger work, has been retained in the abridgement. In the latter, as in the former, the student will find those wonderful revelations in histogeny which make an era in the history of physiology, and which, although the last discovered, must, henceforth, be regarded as essential preliminaries to future descriptions of tissues and organic functions. In these pages, the student will become acquainted with the results of the discoveries and observations of Schleiden, Schwann and Valentin on the formation of the most different elementary tissues of plants and animals, by the development of primitive or nucleated cells out of structureless or unformed gummy and mucous substances,—and of Barry and others on embryology, showing a similar development of various tissues and organs from the ovum, quickened into vital activity by the stimulus of spermatozoa, and growing by the evolution from and addition to its own primitive one, of fresh cells. Similar nucleated cells are found to exist in or rather to make up the globules of the blood, and are readily evolved from coagulated fibrin; proving this fluid to be, conformably with long observation, the formative and vitalizing one. From these facts, in perfect harmony with each other, we are able at last to deduce a general theory of vegetation and organisation.

So important are the new views of histogeny, that it has been thought advisable to transfer the chapter containing them from the end of the large work, where it was placed, to the beginning of Special Physiology in the present volume. In natural relation to the subject of the original formation of the tissues, is that of their regeneration or reproduction, with or without inflammation, and, on this account, the description of the latter is removed from the place which it occupied to that immediately following histogeny. Another deviation from the arrangement of the author will be found in bringing in the chapters on Digestion immediately after those on Respiration, in place of letting them remain after Nutrition and Secretion; and in making the chapters on Secretion precede those on Nutrition and Growth, rather than allow them to follow, as they do in the original. The progressive order of the changes to which aliment is subjected, from its introduction into the stomach to its conversion into blood, and the consequent metamorphosis of this fluid into secretions and matters for nutritive deposit and the growth of the tissues, are exhibited better in the modified than in the original arrangement.

A few notes at the foot, and some paragraphs in the body, of the page, have been added by the editor, who did not feel himself free to do much in this way, when his office was to abbreviate and arrange.

His additions are designated by the letter (*a*). More numerous and important are the additions made by the translator, some of which furnish corroborative facts and references to the text, and occasionally qualify the propositions advanced in it. Distinct mention has not always been made in this volume of the contributions of Dr. Baly, nor could they, it was feared, without embarrassing the reader, be distinguished in this as they are in the London edition, by circumflex marks, [ ]. But it would be ungrateful to let the occasion pass without acknowledgments to that gentleman for the good, healthy English into which, for the most part, he has rendered the German original.

With the exceptions just stated, not only his manner of treating the various subjects, but the language of the author, has been preserved throughout; and hence, when it shall be discovered, as it readily may, by a comparison of the contents and index with those of the London edition, that there is scarcely a fact or proposition in human physiology, and none of either applied to hygiene, pathology or therapeutics, in the original work, as translated by Dr. Baly, that is not met with in the present volume, it will not be considered too much to say, that this latter contains emphatically Müller's "Elements of Physiology," with nearly all the characteristics which give it value in the eyes of the student. So earnest has been the desire of the editor to complete in a suitable manner his arrangement of the work, that he has retained nearly all the bibliography, which manifests the extensive reading and research, as well as love of accuracy, of the author. Not only did this measure seem to be due to Müller himself, but also to his readers in this country, the latter of whom will have it in their power, when quoting Müller, to repeat his references to all the authors on every leading question in physiology, and to carry out, if they desire it, an independent course of inquiry for themselves.

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PROLEGOMENA

ON GENERAL PHYSIOLOGY.

PHYSIOLOGY is the science which treats of the properties of organic bodies, animal and vegetable, of the phenomena they present, and of the laws which govern their actions. Inorganic substances are the objects of other sciences,—physics and chemistry.

In entering upon the study of physiology, the first point to be ascertained regards the distinctions between these two great classes of bodies—the organic and the inorganic,—and the following questions suggest themselves for discussion:—Do organic and inorganic substances differ in their material composition? and if the phenomena presented by them are obviously different, are the forces or principles on which these phenomena depend, also different; or are the forces which give rise to the phenomena of the organic kingdom merely modifications of those which produce physical and chemical actions?

1. OF ORGANIC MATTER.

Nothing analogous to sensation, nutrition, or generation, is observed in inanimate nature, and nevertheless the matter which composes organic bodies consists of precisely the same elements as inorganic matter. In examining the composition of organic bodies, it is true, we meet with substances—the proximate principles, or *principes immediats*—which are peculiar to them, and cannot be produced artificially by any chemical process; such are fibrin, albumen, gelatin, &c. But all these substances may be reduced by chemical analysis to the same simple elements which constitute minerals. Of these simple substances, all entering into the composition of inorganic bodies, there are fifty-two. In organic bodies there have been discovered but eighteen.

The elementary substances which are met with in plants are:—

1. Carbon, 2. Oxygen, 3. Hydrogen,	their most essential components.
4. Nitrogen,	found less frequently.
5. Phosphorus, 6. Sulphur,	. . principally in vegetable albumen and gums, especially in the tetradynamia, combined with nitrogen.
7. Potassium,	. . almost universally.
8. Sodium,	. . principally in marine plants.

9. Calcium,	. . almost universally.
10. Aluminium,	. . rarely.
11. Silicium,	
12. Magnesium,	occurring rarely.
13. Iron, 14. Manganese,	. . frequently.
15. Chlorine.	
16. Iodine, 17. Bromine,	occurring in marine plants.

The same substances, with the exception of aluminium, are met with likewise in the animal kingdom. Here sodium is more frequent, potassium less frequent than in plants; iodine and bromine occur in some marine animals.

In man and the higher animals the components are:—

1. Oxygen,	
2. Hydrogen,	
3. Carbon,	
4. Nitrogen,	
5. Sulphur,	met with principally in the hair, albumen, and brain.
6. Phosphorus,	. . . . . in the bones, teeth, and brain.
7. Chlorine, 8. Fluorine, 9. Potassium, 10. Sodium, 11. Calcium, 12. Magnesium,	. . . . . in the teeth and bones.
13. Manganese, 14. Silicium,	found in the hair.
15. Iron,	. . in the blood, pigmentum nigrum, and crystalline lens.

Copper also has been found by Meissner, and more recently by Sarzeau* in plants. Beecher asserts that he has found gold also in the ashes of tamarinds.†

The number of the elements which enter into their composition, constitutes, then, the first difference between organic and inorganic bodies. All the elementary substances found in the inorganic kingdom do not enter into the composition of organic bodies; and some are even inimical to their life.

The mode in which the elements are combined forms a second distinguishing character; and the peculiarity of organic matter depends probably on the following circumstances, first pointed out by Berzelius and Fourcroy:—

1. In mineral substances the elements are always combined in a binary manner; thus, two elementary substances unite together, and this binary compound unites again with another simple substance, or with another binary compound. For example, carbonate of ammonia is constituted of carbon, oxygen, hydrogen, and nitrogen, combined as follows:—

Carbon, Oxygen,	unite to form carbonic acid,	which again unite to form carbonate of ammonia.
Hydrogen, Nitrogen,	. . . ammonia,	

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* Ann. de Chem. et de Physique, xliv. 334.

† Tiedemann's Physiology, translated, with notes, by Drs. James Manby Gulley, and J. Hunter Lane, p. 6.

In minerals the elementary substances are never observed to combine three or four together, so as to form a compound in which each element is equally united with all the others. This, however, is the case in organic bodies. Oxygen, hydrogen, carbon, and nitrogen, the same elements which by binary combination formed inorganic substances, unite together, each with all the others, and form the peculiar proximate principles of organic beings. These compounds are termed ternary, or quaternary, according to the number of elements composing them. Vegetable mucus, starch, and adipose matter are ternary compounds of oxygen, carbon, and hydrogen: gum, albumen, fibrin, animal mucus, and resin are quaternary compounds, their fourth ingredient being nitrogen.(*a*)

A doubt has recently been thrown upon this theory of the composition of organic substances; but there is still great probability in its favour, more particularly with reference to the higher organic compounds, such as albumen, fibrin, &c. Though it is certainly true that there are products formed from organic matter, which have a binary constitution; such, for example, is alcohol, which is a compound of ether and water.

It must at any rate, however, be admitted, that the mode in which the ultimate elements are combined in organic bodies, as well as the energies by which the combination is effected, are very peculiar; for, although they may be reduced by analysis to their ultimate elements, they cannot be regenerated by any chemical process. Berard, Proust, Dobereiner, and Hatchett believe, indeed, that they have succeeded in producing organic compounds by artificial processes; but their results have not been sufficiently confirmed. Woehler's experiments afford the only trustworthy instances of the artificial formation of these substances; as in his procuring urea and oxalic acid artificially. Urea, however, can be scarcely considered as organic matter, being rather an excretion than a component of the animal body. In the mode of combination of its elements it has not perhaps the characteristic properties of organic products.

2. Another essential distinction pointed out by Berzelius is, that in organic products the combining proportions of their elements do not observe a simple arithmetical ratio. Thus, for example, among the large number of different fatty matters which Chevreul has

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(*a*) It is now ascertained that albumen, fibrin and casein, although they differ in external character, contain exactly the same proportion of organic elements. Each of them furnishes by solution in caustic potash and, after decomposition has begun, by subsequent precipitation by acetic acid a gelatinous translucent precipitate. This has exactly the same characters and composition, from whichever of the above three substances above mentioned it has been obtained. It has been called by Mulder, its discoverer, *proteine*, who found that it contains the same organic elements, and exactly in the same proportion, as the animal matters from which it is prepared. Mulder further ascertained, that the insoluble nitrogenized constituent of wheat flour (vegetable fibrin) when treated with potash, yields the very same product, proteine; and it has recently been proved that vegetable albumen and casein are acted on by potash precisely as animal albumen and casein are.—*Liebig—Animal Chemistry.*

examined, many, according to his experiments, differ only by fractional parts in the numerical proportions of their atoms.

3. Organic bodies, animal and vegetable, consist chiefly of combustible matter, which, except in the acids, is constituted of carbon and hydrogen, combined with oxygen in quantity not sufficient to saturate the other elements.*

Their tendency to decomposition.—The matter forming organic bodies has a constant tendency to undergo decomposition; it is only the continuance of life which preserves it: even during life the balance which maintains its elements in their peculiar combination, may be destroyed by the agency of certain simple inorganic bodies, or binary compounds of these, as we witness in the cauterisation of parts of the living body. At some period or other, this change necessarily ensues spontaneously in every living being; the state or influence which maintains the elements in their peculiar combinations becomes more and more feeble, and is, at length, no longer able to counteract the tendency of these elements to form binary compounds among themselves and with other simple substances in the atmosphere around them. Organic matter is thus annihilated, and with it the organized being of which it formed part. In ceasing to present the phenomena of life, it falls under the influence of the laws which govern the formation of chemical compounds; presenting the phenomena of fermentation and putrefaction, and giving origin to a foul smell when the substance contained much nitrogen. Chemical compounds, we know, are regulated by the intrinsic properties and the elective affinity of the substances uniting to form them; in organic bodies, on the contrary, the power which induces and maintains the combination of their elements does not consist in the intrinsic properties of these elements, but something else, which not only counteracts their affinities, but effects combinations conformably to laws of its own operation. Light, heat, and electricity, it is true, influence the compositions and decompositions going on in organic bodies; as they do those in inorganic bodies; but nothing justifies us in regarding, without further inquiry, any one of the imponderables,—heat, light, and electricity,—as the ultimate cause of vital actions.

After the cessation of life, organic substances always undergo decomposition, if the conditions necessary for the exertion of chemical affinity are present. The products of this decomposition are nitrogen and hydrogen, (which partly escape in a free state,) water, carbonic acid, carburetted hydrogen, olefiant gas, ammonia, cyanogen, prussic acid, phosphuretted hydrogen, and hydrosulphuric acid; while in some cases the elements reunite in different proportions so as to form a new organic compound, as in the production of sugar from starch in the saccharine fermentation.

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* haracters of organic matter will be found more fully Gmelin, in their classical text-books of chemistry, and tion of Hildebrandt's Anatomie des Menschen, vol. i.

Sometimes from one organic substance two new compounds are generated,—one organic, the other inorganic,—as in vinous fermentation, during which carbonic acid and alcohol are formed from sugar. Decomposition does not commence in the bodies of animals and plants immediately after their death. This Gmelin explains, by supposing that the conditions necessary for the exertion of elective affinity are not then present, just as several inorganic substances require a certain temperature for their decomposition.*

(The conditions more or less necessary for the spontaneous decomposition of organic matter) are moisture, the access of atmospheric air, and a certain temperature. The first is absolutely necessary: organic substances when perfectly dry, do not undergo decomposition at the ordinary temperature of the atmosphere. Air is also often necessary, but not always: moist animal tissues suffer decomposition even when atmospheric air is excluded, (for example, by immersion in fluid mercury,) although the presence of air facilitates putrefaction in the highest degree, even more than oxygen alone. A certain temperature is always necessary.

The gaseous products of the decomposition of animal matter, and of the human body in particular, are carbonic acid, sometimes nitrogen, hydrogen, sulphuretted hydrogen, phosphuretted hydrogen, and ammonia. Acetic acid is also formed, and sometimes nitric acid. The solid matter that remains, consists of the carbonaceous substances, which decompose more slowly, and of the fixed mineral ingredients, earths, oxides, and salts, which with the carbonaceous substances form the soil (*humus.*)† Several parts of the bodies of man and animals immersed in water, or buried in certain situations, even without the access of water, undergo a peculiar change in their being converted into a substance, named adipocire. Berzelius is of opinion, that the fibrin, albumen, and colouring matter of the blood, as well as the adipose matter, may be converted into this substance; while Gay Lussac and Chevreul state that the fat, which can be extracted from fresh animal textures by chemical processes, equals in quantity the adipocire generated by putrefaction in water, and they infer, therefore, that the fat merely is converted into adipocire, while the other tissues are destroyed.

State in which mineral components exist in organic bodies.—The proportions in which the oxygen, hydrogen, carbon, and nitrogen are combined, seem to constitute the chief differences in the composition of organic substances. The organic compounds of these elements especially, are ternary and quaternary, not binary. In what state the less abundant mineral ingredients exist in organic bodies,—whether they likewise enter into the formation of ternary or quaternary compounds, or are merely mingled with them in the binary form,—is an important question which cannot at present be determined. Englehardt has ascertained that the mineral ingredients can be separated from a watery solution of the colouring matter of the blood, and other animal matters, by means of chlorine. From this fact, and from the iron not being extracted by acids, Berzelius infers it to be probable that the iron in the blood is in the metallic state, not in that of oxide; as chlorine has a very strong affinity for metals, and not for oxides, for which acids on the other hand have a great affinity. Professor Henry Rose adduced some experiments which seemed to show that the iron was combined as an oxide with the animal matter, for instance, as an albuminate of the oxide; but Berzelius rejects this idea, for in that case the oxide ought to be extracted by acids from the blood as it is from artificially formed albuminate of iron. For further particulars on this point the reader is referred to the section on the Chemical Analysis of the Blood.

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* Gmelin, Chemie, vol. iii. p. 9.

† See Weber, loc. cit. vol. i. p. 70.

Berzelius cannot decide in what form sulphur and phosphorus exist in animals; whether united with other simple substances in multiple organic compounds, or combined with the ternary compounds of other simple substances so as to form secondary binary compounds, or whether each of these substances, already in a binary form, is again combined with other substances. Vauquelin, by burning the fatty matter of the brain, obtained a cindery mass, which contained so much phosphoric acid, that this latter substance by preventing the access of air arrested the combustion; on removing the phosphoric acid by means of water, the mass again burned for a time, until more acid was formed upon the surface. This cinder, therefore, says Berzelius,* must contain phosphorus in a fixed, not volatile state,—in a state hitherto unknown in inorganic nature.

Many circumstances, however, render it probable that several mineral substances exist in the animal body, in the binary form, as salts or oxides, either mixed or chemically combined with the animal matter. These circumstances are:—1, the appearance of minute microscopic crystals in the animal fluids simply evaporated; 2. the proneness of the mineral substances contained in vegetable tissues to vary with the situation of the plants, which could not be the case if the mineral elements existed in them merely as elements of the organic compounds; 3. the facility with which salts, entering the blood accidentally, are separated from it with the urine; 4. that chlorine of sodium can, as Autenrieth remarks, be separated from solid animal matter by mere washing; 5. the state of the phosphate of lime in the bones. Professor E. H. Weber shows clearly, that the phosphate of lime of the bones does not exist in them as phosphorus, oxygen, and calcium; but that it is in the state of a salt combined—perhaps only mechanically mixed—with the cartilaginous substance, since madder (*rubia tinctorum*), which has a strong affinity for phosphate of lime, but none for lime or calcium, is attracted, during the process of nutrition, by the bones from the blood of an animal fed upon it. Moreover, several acids decompose the salt of lime contained in the bones, and extract it without altering the form or composition of the cartilaginous framework.*

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* Thierchemie, p. 17.

Excluding from consideration the substances which in individual cases may be the educt or product of chemical analysis, we may, with Professor Weber, recognise two classes of binary compounds, as forming part of the animal, and more particularly of the human body.

The first class consists of binary compounds of mineral substances only; such as phosphate of soda, phosphate of lime, phosphate of magnesia, carbonate of soda, carbonate of lime, muriate of potash, muriate of soda, fluoride of calcium, silica, oxide of manganese, oxide of iron, and soda.

In the second class are included binary compounds of organic with mineral or inorganic substances; such as the compound which the albumen is supposed to form with soda in the blood—albuminate of soda—and the salts of lactic acid—lactates of potash and soda.

The simplest forms in which organic matter appears, are now to be considered.

The first form is that of complete solution. There are many fluids containing organic matter, in which no visible molecules can be discovered; such, for instance, is the serum of blood until it is subjected to the influence of heat, galvanism, or different chemical agents. A part of the animal matter of the lymph and chyle is also in the state of solution.

The second form is the state of softness which the solid organised tissues present, and which is peculiar to organic beings. The tissues derive their properties of extensibility and flexibility from the water, which constitutes four-fifths of their weight; although they cannot be said to be wet, and do not impart their water to other substances so as to moisten them. This water, as Berzelius remarks, appears not to be chemically combined in them; for it is gradually given off by evaporation, and can be extracted at once by strong pressure between blotting-paper. When deprived of its water, animal matter becomes wholly insusceptible of vitality; except in the case of some of the lower animals, which, as well as some plants, revive when again moistened.† According to Chevreul, pure water alone can reduce organized substances to this state of softness; although salt water, alcohol, ether, and oil are also imbibed by dry animal textures. Moist animal tissues, by virtue of their porosity, allow soluble matters, which come into contact with them, to be dissolved by the water which they contain, and which fills their pores; if the matters are already in solution, they are imparted by their solutions to the water of the tissues. Gaseous substances are taken up in the same way. Matters, also, which are contained in solution in one tissue, are rapidly imparted to other tissues which can dissolve them. The laws of the attraction of substances in solution, the laws governing the uniform distribution of miscible fluids, are therefore also applicable in the case of moist animal tissues.*

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* Weber, loc. cit. p. 318, 340.

† Berzelius, Thierchemie, p. 7.

Organic substances are, during life, never crystallised, and the excreted matters of animals which are crystallizable, viz. urea, lithic acid, and some fatty matters, are never found crystallized in the living tissues, except in their diseased states, although crystallized mineral substances are sometimes observed in the cells of plants.

The organic matter frequently appears in the form of microscopic molecules. These organic molecules are observed sometimes in fluids: such are the red particles of the blood which in man measure from $\frac{1}{3700}$ to $\frac{1}{4600}$ of an inch; the globules of the chyle which measure $\frac{1}{7199}$ of an inch, according to Prevost and Dumas; and those of the saliva, which measure $\frac{1}{3770}$ of an inch, according to Weber. The small bodies contained in the chyle, milk, and bile, are globular; those of the blood are, in mammalia, round, but flattened; and in birds, reptiles, amphibia, and fishes, oval as well as flattened. The blood corpuscules always consist of a nucleus inclosed in an outer envelope. The globules of coagulated albumen and fibrin are less distinct. Many of the tissues even of organized bodies, particularly of animals, appear to consist of molecules aggregated in the form of fibres, lamellæ, and membranes. These molecules are most distinct in the brain, and in the embryo, for instance, in the germinal membrane of the ovum; in other tissues, it is by no means certain that the appearance of molecules, observed under the microscope, is not an illusion produced merely by inequalities of the surface. The opaque part of the germinal membrane in the ovum of the bird is evidently composed of globules of considerable size, which are visible with a simple lens, and are perfectly similar to the globules of the yolk; but even the vessels which are distributed through the germinal membrane are, according to my observations, formed of an incomparably finer matter; as are also the central transparent part of the germinal membrane, the *area pellucida*, and the embryo itself. It appears, indeed, that the germinal membrane is formed by the attraction and aggregation of the globules of the yolk; but all the parts developed in this germinal membrane are produced by solution of these globules, and conversion of them into a matter in which no elementary particles can be distinctly recognised, and of which the molecules must, at any rate, be beyond comparison more minute than the globules of the yolk and germinal membrane.

The ultimate muscular fibre in the frog is from five to eight times more minute than the red particles of its blood, and more minute even than the nuclei of these red particles; the thickness of the muscular fibre in the frog and in Mammalia is nearly the same, while the size of the red particles of the blood in the two is very different. The diameter of the ultimate nervous fibre in Mammalia is, according to my observation, twice or three times less than that of their blood corpuscules, and is greater than that of the nuclei of the blood corpuscules. In the frog, the primitive nervous fibre has only $\frac{1}{8}$th the diameter of its blood corpuscules, and is therefore much smaller than the nucleus of the blood corpuscule. I have not been able to satisfy myself that the nervous fibrils consist of globules arranged in a linear form. They certainly present successive inequalities, but these inequalities are not regular. In fine, this theory of the composition of tissues by the aggregation of globules, which are supposed to be more than $\frac{1}{3000}$ of a line in diameter, is rendered exceedingly improbable by the discovery of Ehrenberg, that monads, which themselves do not measure more than $\frac{1}{3000}$ of a line, have compound organs. On account of the difficulty of distinguishing by the microscope between inequalities and globules, this theory still remains a mere hypothesis. At any rate, the organic molecules are merely the most minute forms in which the compound organic matter appears; they are not the atoms of the organic combination. The hypothesis that all the tissues of the animal body are, in their perfect state, composed of globules aggregated together in different forms, is now known to be wholly incorrect. The nervous fibres, for instance, are delicate tubes of perfectly smooth and homogeneous structure, enclosing a fine granular substance. The cellular tissue, when perfectly developed, consists of smooth cylindrical fibres. The interesting discovery has been made, however, that most probably all tissues are originally developed from bodies of similar form, the primary or formative cells, as will be explained hereafter.

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* See the observations on imbibition in the Section on Absorption by the capillaries.

Source of organic matter.—It is only in organic bodies themselves that the peculiar force which animates them is observed. It is manifested only in the organic compounds produced in these bodies; the mere accidental coming together of the elementary components is not capable of producing organic matter. Fray, it is true, asserts that he has observed the formation of microscopic Infusoria in pure water; and Gruithuisen says, that he has seen a gelatinous membrane form in infusions of granite, chalk, and marble, and infusory animalcules subsequently appear in this membrane. The fact observed by Retzius* is also remarkable; namely, that a peculiar kind of Conferva was generated in a solution of muriate of baryta in distilled water, which had been kept half a year in a bottle closed with a glass stopper. But, in these remarkable cases, it is certain that either the vessels, or the water, contained organic matter, however small may have been the quantity; and, according to the experiments of Schultze, the most minute particles of organic matter in the form of dust are sufficient, under favourable circumstances, to produce the phenomena which have been regarded as instances of equivocal generation.

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* Froriep's Notizen, v. 56.

Even animals themselves have not the power of generating organic matter out of simple inorganic elements or binary compounds, but grow by the assumption of matter already organized, whether animal or vegetable;—they have the power of preserving organic compounds and of converting one into another, but they cannot produce them. Plants, on the contrary, seem to be able not merely to assimilate the organic matter of animals and vegetables; but also to generate it from simple elementary bodies and their compounds, such as carbonic acid and water, although the presence of some organic matter in the soil in which plants grow, is necessary. It seems impossible to deny this production, by plants, of organic matter from inorganic compounds; for, unless such were the case, the nutriment on the earth would be constantly decreasing in quantity, since animal and vegetable matters are being incessantly converted by combustion, putrefaction, &c. into binary compounds.

The organic matter formed by plants, or that contained in plants and animals, and modified by them, is capable of again forming a part of other living beings, when taken into them and subjected to their vital forces. In this manner all the organic matter which is spread over the surface of the earth, originates in living beings. Death, that is, the extinction of the power which produces and maintains organic compounds, annihilates the individual; while the organic matter which formed this individual, as long as it is not reduced to binary compounds, is still capable of receiving new life, or, in other words, of nourishing other living bodies.

Equivocal generation.—The ordinary mode of production of organic beings is from others of the same species, by ova or shoots. But we must inquire, whether the organic matter left after the destruction of one living body can, under certain circumstances, generate living bodies of another kind; whether it is capable, not only of nourishing bodies already living, but also of continuing its own life in a modified form; whether, in fact, under certain conditions,—namely, under the influence of atmospheric air, water and light,—small microscopic animals, the Infusoria, and under other conditions the simplest plants, forming mould, are generated from this apparently dead organic matter.

In a more extended sense the ancients, especially Aristotle, had admitted this equivocal generation, this spontaneous formation of animals; for they had an old tradition, that the lower animals, insects and worms, were generated during putrefaction. This opinion was still maintained among the other superstitions of natural history and medicine even in the seventeenth century. At that period Redi wrote his "*Experimenta circa Generationem Insectorum,*" in which he proved that all the instances of equivocal generation, which the older writers had adduced, were erroneous; that all these worms and insects were produced from ova which had been previously deposited. His proofs were convincing, and from that time no well-informed naturalist believed in the fable of generation by putrefaction; so that the proverb "*Omne vivum ex ovo,*" retained its force. Subsequently, however, Needham* pointed out, that although no insects are produced by putrefaction, yet that, during that process, minute microscopic animals, till then unknown, are generated. If water is poured over animal or vegetable substances, and the infusion exposed to air and light at the usual temperature of summer, after a few days the organic matter will have undergone partial decomposition, being in part converted into other organic matters, partly reduced to globules, and in part dissolved; and there will appear in it either mould, or those microscopic animals, in which Ehrenberg has discovered a very complicated organization.

Since the time of Needham, our knowledge of this subject has been extended by the observations of Wrisberg, O. F. Müller, Ingenhouss, G. R. Treviranus, Gruithuisen, and Schultze.

If we criticise the observations of these writers, we shall find that the mode in which their experiments have been performed do not leave the results in favour of equivocal generation free from doubt. In the various experiments which they have made, it is not certain: 1. That the Infusoria or mould did not arise from the dust of desiccated animalcules, or their germs, floating in the air: 2. That the water may not have contained the ova of Infusoria, or animalcules themselves, which have afterwards multiplied rapidly at the expense of the organic matter in the Infusoria: 3. That these ova and animalcules have been in some way contained in the organic substances and distilled water, or even freshly prepared gases used in the experiments.

Lastly, although some experimenters should have employed organic substances long boiled, with distilled water and artificially prepared air at the same time, still the accuracy necessary for a sure result is neither probable nor generally possible; since every instrument used for changing the water ought to be absolutely free from particles of organic matter, and every cleansing is a source of errors.

Ehrenberg's observations are opposed to the theory.—The foregoing remarks do not disprove the existence of equivocal generation; they merely show that it is scarcely possible to prove it by direct experiment. The investigations of Ehrenberg, however, relative to the organization of those animals and plants, which are supposed to be generated in this "equivocal" manner, have thrown new doubt upon the theory. In the first place, Ehrenberg discovered the real germs of the fungi and algæ, or mould.* The propagation of these organic bodies was thus established; it was shown that, by means of the germs or seeds of the mould, new mould can be produced, which rendered it probable that the cases of the unexpected production of mould arose merely from germs, which had been diffused in the atmosphere or water, having then found the situation required for their development. With regard to the infusory animalcules, their complicated structure was first discovered by Ehrenberg; he found that the smallest monad $\frac{1}{2000}$ of a line in diameter has a complicated stomach, and organs of motion, in the form of cilia. In others he observed the ova, and the propagation by ova. This excited the greatest doubt with regard to those earlier observations, in which, the complicated structure of these animalcules being unknown, they were said to have been seen to originate in particles of the organic substance of the infusion. Ehrenberg has never succeeded in obtaining determinate forms of Infusoria, according to the nature of the infusion; and even by the most similar modes of performing the experiment, sometimes one, sometimes another set of animalcules were obtained. He believes that there are certain forms, of which the number is limited, which are most widely diffused; that the ova or individuals of these forms may exist in all waters, even in some parts of plants, but perhaps only in the noxious parts; and that, of these forms, different kinds may be much multiplied, according to the kinds of ova or individuals which were in the water, or were introduced into it. The increase of these animals appears to be extraordinarily rapid. A single wheel-animalcule, *Hydatina senta*, which was watched for more than eighteen days, and which lives still longer, is capable of a fourfold increase in twenty-four or thirty hours; a rate of propagation which would afford in ten days a million of beings. This, in some measure, explains the extraordinary number of Infusoria in a drop of an infusion. Ehrenberg never observed any animalcules in dew or rain; but there are some which he has found in Africa and Asia as well as in Europe, in sea water as well as in river water, in the depths of the earth and at its surface. During their development, however, these animals seem to present many forms, and the forms dependent on the different stages of development of one animalcule may be easily mistaken for examples of different species. From these observations Ehrenberg concludes, that all Infusoria are, like other animals, propagated from ova,—*omne vivum ex ovo*,—and leaves it undecided whether the ova are, or are not, in part really the product of a *generatio primitiva*.†

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* Nouv. Observ. Microscop. and "New Microscopic Discoveries," London, 1745.

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* Nov. Act. Nat. Cur. t. x. See also Nees. v. Esenbeck, Flora, 1826, p. 531; and Schilling in Kastner's Archiv. x. 429.

† Ehrenberg in Poggendorf's Annal. 1832. 1. See also Wagner in the Isis for 1832.

Facts relating to Entozoa, favourable to equivocal generation.—The alleged primitive formation of certain animals from unorganised animal matter, is still best supported by certain facts respecting the Entozoa. A complete series of arguments in favour of equivocal generation rests upon the impossibility of explaining the first production of Entozoa, without supposing a spontaneous generation. 1. The immense majority of the intestinal worms are quite distinct in their organisation from all the beings which are met with out of the animal body. The similarity of some *Distomata* to the *Planariæ* of fresh and salt water is only apparent. 2. A small number only of intestinal worms occur in different genera of animals. Thus the Tænia of man is peculiar to him; though, on the contrary, the *Distoma hepaticum*, or liver fluke, seems to be common to man, the hare, cow, camel, deer, horse, and hog; the thread-worm, Ascaris lumbricoides, is common to man, the hog, ox, and horse. Most animals have their peculiar Entozoa, differing specifically from those of others. 3. Many of these Entozoa occur only in particular organs. 4. Intestinal worms generally die when removed from the animal body. 5. They have been observed even in the embryo. 6. The fact of animals, which feed on vegetables solely, having nevertheless their own peculiar Entozoa, proves that these Entozoa, or their germs, cannot be introduced with the food. Even in carnivorous animals the introduction of the Entozoa from without can be admitted in very few cases only: such are the facts of the Echinorhynchus of the field-mouse having been sometimes found in the falcon; the worms of the frog, in serpents; and the Ligula of fishes, the *Bothriocephalus solidus* of the stickleback, in the intestines of wading and swimming birds; while many other Entozoa are met with in other parts than the intestinal canal, and beyond the reach of matters introduced from without.*

Ehrenberg endeavours to set aside the equivocal generation of the Entozoa; inclining to the old opinion that the ova of these animals circulate with the fluids in all parts of the body. But the suppositions by which the equivocal generation is thus sought to be refuted, are as improbable as that theory itself. The ova of the Entozoa are evidently too large to enter the lymphatics of the organ in which the worms live; they are much too large to circulate in capillary blood-vessels, of which the diameter is only $\frac{1}{3700}$ of an English inch, or in fine to pass into the secretions,—the milk, or yolk of the egg, for example: the explanation of the occurrence of Entozoa in herbivorous animals, by transmission from mother to young, is consequently completely opposed to the known data afforded by the micrometer, unless it be admitted that the smallest particle of the germinal matter formed by Entozoa already existing, is as capable of propagating them as an entire ovum. With regard to the Spermatozoa, Ehrenberg assumes that every animal receives them at the time of fecundation. Direct experiments relative to the question of equivocal generation are, in the present state of science, necessarily attended with extreme difficulty. Those, however, which have been instituted most recently are unfavourable to the hypothesis. Fr. Ferd. Schultze has observed that atmospheric air, after being passed through sulphuric acid, is no longer capable of giving rise to the development of Infusoria in fluids which have been subjected to long boiling; and Schwann found that neither the production of Infusoria or algæ (mould), nor putrefaction took place in boiled fluids, when the air in contact with them had been exposed to a great heat, though it still contained abundance of oxygen, and was frequently renewed.

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* Bremser, Ueber lebenden Würmer im lebenden Menschen. Wien, 1819.

M. Von Baer* has observed many extraordinary circumstances in the generation of the Entozoa. The animals which he names Bucephalus, are generated in thread-like ovistocks, which are found in mussels; and Bojanus and Baer have described a worm, found in the Lymnæus stagnalis, which again contains numerous animals of a perfectly different form,—namely, Cercariæ.† Nordmann‡ has seen monads in the body of living Diplostomata, and has observed the production of infusory animalcules in the interior of the putrefying ova of Lernææ. On the other hand, the changes which certain Entozoa undergo deserve attention; for example, the *Ligula* and *Bothriocephalus solidus* of fishes have no distinct genital organs until they are received into the intestines of water birds: some young Distomata have at first a different form from that which they afterwards present; thus the Distoma nodulosum of the perch has, according to Nordmann, at first no sucker, and is, then, provided with a trace of an eye and with cilia, as if to swim in water. The Infusoria and Entozoa of living plants still require investigation. It is important to know, that the diseased grain of Agrostis or bent-grass, Phalaris or canary-grass, and wheat, contain, according to Steinbuch§ and Bauer,‖ Vibriones; that Bauer, having inserted Vibriones into the stem of the young wheat, found them again in the grain; and that the worms of the dried seeds, according to the same observers, if placed in water after several years, will again present all the phenomena of life.

Origin of organic matter and of the organic force.—In the production of Infusoria there is no new formation of organic matter; the previous existence of organic beings is presupposed. Organic matter is never produced spontaneously. Plants alone seem to have the power of generating ternary or organic compounds from binary or inorganic compounds; while animals are nourished only by organic matter, which they cannot generate from binary compounds, and consequently their existence presupposes that of the vegetable kingdom. How organic beings were originally produced, and how organic matter became endowed with a force which is absolutely necessary to its formation and preservation, but which is manifested only in it, are questions beyond the compass of our experience and knowledge to determine. The difficulty is not removed by saying that the organic force has resided in the organic matter from eternity, as if organic force and organic matter were only different ways of regarding the same object: for, in fact, the organic or vital phenomena are presented only by a certain combination of the elements; and even organic matter, itself susceptible of life, is reduced to inorganic compounds as soon as the cause of the vital phenomena, namely, the vital force, ceases to exist in it. This problem, however, is not a subject of experimental physiology, but of philosophy. Conviction in philosophy and in natural science have entirely different bases; the first suggestion here, therefore, is, not to be led away from the field of rational experiment. We must be content to know that the forces which give life to organic bodies are peculiar, and then examine more closely their properties.

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* Nov. Act. Cur. xiii. 2.

† Compare Siebold, on the anatomy of monostomum mutabile, Wiegmann, Arch. i. 35. Carus on the Leuco-chloridium paradoxum. Nov. Act. Cur. Nat. xvii. 1.

‡ Microgr. Beiträge. Berlin, 1832.

§ Analecten. 1802.

‖ Philos. Trans. 1823.

II. OF ORGANISM AND LIFE.

Organised beings are composed of a number of essential and mutually dependent dissimilar parts.—The manner in which their elements are combined, is not the only difference between organic and inorganic bodies; there is in living organic matter a principle constantly in action, the operations of which are in accordance with a rational plan, so that the individual parts which it creates in the body, are adapted to the design of the whole; and this it is which distinguishes organism. Kant says, "The cause of the particular mode of existence of each part of a living body resides in the whole, while in dead masses each part contains this cause within itself." This explains why a mere part separated from an organised whole generally does not continue to live; why, in fact, an organised body appears to be one and indivisible. And since the different parts of an organised body are heterogeneous members of one whole, and essential to its perfect state, the trunk cannot live after the loss of one of these parts.

It is only in very simple animals or plants which possess a certain number of similar parts, or where the dissimilar parts are repeated in each successive segment of the individual, that the body can be divided, and the two portions, each still possessing all the essential parts of the whole, though in smaller number, continue to live. Branches of plants separated from the trunk, being planted, form new individuals. The different parts of plants are so similar, that they are convertible one into another, branches into roots, and stamens into petals.* This is the case also with some simple polypes. The experiments of Trembley, Roesel, and others, prove that portions of a divided polype will continue to grow until each half becomes a perfect animal. In the same way some worms, as the Naïdes, in which each segment contains nearly the same essential parts,—the intestine, nerves, and blood-vessels, —have been observed to propagate by spontaneous division. Bonnet states, that he has seen this new growth and reproduction in the portions of a divided earthworm: but this animal, when thus divided, could not continue to live; for neither portion would contain all the parts essential to the whole.

In the higher animals, and in man, there are certain organs,—that is, parts differing in their properties and functions,—which cannot be removed without destruction of life, and of our idea of the whole; and such organs also only occur singly, as brain, spinal marrow, lungs, heart, and intestinal canal. Other parts, on the contrary, which are not members essentially necessary to our idea of the whole being, or which are several in number, may be removed with impunity: no part, however, of one of the higher animals can continue to live when separated from the body, for no one part contains all the organs essential to the whole. The ovum, the germ itself, alone possesses this power; for, at the time of its separation from the parent animal, the vital force has not formed in it the essential parts of the whole; and yet it becomes developed into a new integral being. There is, then, a unity in the organism, to which its composition of dissimilar parts is subordinate. From the facts above stated, however, it appears that organised bodies are not absolutely indivisible; they may, indeed, always be divided, and still retain their properties, if each portion contains the essential heterogeneous members of the whole, and in the generation even of the highest animals and plants a division takes place.

Inorganic bodies are divisible in a much more extended sense, without the parts losing the chemical properties of the whole; they may be divided (to use the common expression) *ad infinitum*,—that is, according to the atomic theory, into the ultimate atoms which, on account of their minuteness, elude the senses; and in chemical compounds, into molecules which are formed of the different component atoms, and which are likewise not recognisable by the senses. To this character of inorganic bodies, however, crystals form an exception, since they cannot be reduced by division to their ultimate particles without losing some of their properties.

Adaptation displayed in organised bodies.—Organised bodies being composed of a certain number of dissimilar essential parts all adapted to the plan of the whole individual, it necessarily follows that their external and internal conformation are such as to distinguish them entirely from inorganic bodies. There is a harmony between their form and organisation, and the functions which they are called upon to perform. In crystals there is no such adaptation: their increase is by apposition and aggregation. That of organised bodies is by internal changes going on contemporaneously in different parts.*

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* Goethe, Metamorphose der Pflanzen.

This law of organic conformation,—adaptation to an end,—regulates the form, not only of entire organs, but also of the simplest elementary tissues. Thus it will be shown, in a future page, that the manifold forms of secreting glandular structures depend simply on the various modes in which a large secreting surface can be made efficient in a small space. The fibrous structure of muscles is necessary to enable these organs to shorten themselves in a determined direction by the zigzag flexure of the fibres. So, also, in treating of the Physiology of the Nerves it will be shown, that unless the nerves had been divided into a certain number of primitive fibres, which do not communicate one with another, their local action,—local circumscribed sensation,—would be impossible. The same adaptation is seen to be equally necessary in the organisation of plants. The organs of plants are less heterogeneous; and, in place of being so much enclosed in the interior, are expanded on the surface,—the reciprocal actions with the external world being effected by the whole surface rather than by particular points. Hence the general character of the conformation of plants is that extension of surface which is effected by means of the various forms of leaves, in ways more manifold than the most lively fancy could have imagined; so that a great part of botanical terminology is only an attempt to form, logically and conformably to nature, a scheme of the possible varieties in the increase of surface produced by variations of the leaves, and of their relation to pedicle, twig, branch, and stem.

Organic symmetry as distinguished from inorganic.—The only character that can be possibly compared in organic and inorganic bodies, is the mode in which symmetry is realised in each. Crystals have symmetrical and asymmetrical surfaces, angles, and corners. Animals have also symmetrical and asymmetrical parts, and the laws of symmetrical and asymmetrical conformation present in organised bodies, as in crystals, manifold variations. The original form of the animal germ, for example, is a roundish flat disk,—the cicatricula (germinal disk, blastoderma) in the bird's egg; this germinal disk, while in the ovary, appears, from the researches of Purkinje and Baer, to be a vesicle. The germ is also disk-shaped in invertebrate animals, as I have seen in the Planaria. The form of the ovum and yolk must not be confounded with that of the germ. In addition to the circumstance that the symmetry and asymmetry of crystallised inorganic bodies are always represented by plane surfaces and straight lines, the reverse of which is the case in organised bodies, there is also this great difference, that the symmetrical and asymmetrical parts of crystals have a simple composition, while the symmetrical parts of organised bodies are themselves in the first place formed of heterogeneous tissues. The causes which give rise to the different types of organic symmetry, and which first determine in the germ the position of the axis for the symmetrical development, are as difficult to imagine as the causes of the symmetry of form in crystals.

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* Professor E. H. Weber has made some other very interesting comparisons between organisation and crystallisation in his General Anatomy. Hildebrandt's Anat. 1^{ter} Band.

The *component tissues of organised bodies are never crystalline;* for although some kinds of fatty matter are crystalline in the pure state, it is only when they are subjected to external influences and withdrawn from that of life. The same is the case with sugar, urea, and lithic acid. Most of the organic substances and fluids do not crystallise even when removed from the living body. The spinal canal and the cranial cavity of the frog have, indeed, surrounding the central parts of the nervous system, a layer of white pulpy matter which, according to Ehrenberg and Huschke, consists of microscopic crystals of carbonate of lime. So, also, in the peritoneum of fishes, and in the tapetum of the choroid of the same animals, Ehrenberg* has discovered microscopic crystals composed of organic matter. The pulverulent matter in the labyrinth of the ear consists of microscopic crystals. The chorion of the ova of lizards, and the gritty matter of the pineal gland, and choroid plexus of the human brain, the dental pulp of the human subject and of some Mammalia, and peculiar sacculi in the earthworm, described by Henle, contain particles which, according to Valentin,† exhibit an imperfect crystalline form and arrangement. The presence of minute crystals, called raphides, in the tissues of many plants and generally within the cells, is well known. In diseased states, crystallisation not unfrequently takes place within the body; sometimes apparently the immediate result of the morbid process, as in the formation of certain arthritic concretions; but more frequently perhaps in consequence of subsequent chemical changes ensuing in matters already eliminated from the vessels, or of the removal of a part of the solvent fluid. To these causes we must refer most biliary and urinary calculi, and the crystals of calcareous and soda salts formed in the crusts of the intestinal ulcers, and in the intestinal excretions in Typhus, as well as in carcinomatous tumours, the discharges from gangrenous parts, &c. as observed by Schœnlein (Müller's Archiv. 1836, p. 258), Valentin (Repertor. Bd. ii. p. 262. Bd. iii. p. 534), and Gluge (Müller's Archiv. 1837, p. 463).

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* Müller Archiv. für Anat. und Physiolog. 1834, p. 158.

† Repert. für Anat. u. Physiol. Bd. i. p. 2.

The organic force is creative.—Hitherto, I have examined merely that peculiarity of organised bodies which consists in their being systems of dissimilar organs, the existence of each of which has its source, not in itself, but in the entire system, as Kant expressed it. *The organic force*, which resides in the whole, and on which the existence of each part depends, has however also the property of generating from organic matter the individual organs necessary to the whole. Some have believed that life,—the active phenomena of organised bodies,—is only the result of the harmony of the different parts—of the mutual action, as it were, of the wheels of the machine,—and that death is the consequence of a disturbance of this harmony. This reciprocal action of parts on each other evidently exists; for respiration in the lungs is the cause of the activity of the heart, and the motion of the heart at every moment sends blood, prepared by respiration, to the brain, which thus acquires the power of animating all other organs, and again gives occasion to the respiratory movements. The external impulse to the whole machinery is the atmospheric air, in respiration. Any injury to one of the principal moving powers in the mechanism, any considerable lesion of the lungs, heart, or brain, may be the cause of death; hence these organs have been named the *atria mortis*. But the harmonious action of the essential parts of the individual subsists only by the influence of a force, the operation of which is extended to all parts of the body, which does not depend on any single organ, and which exists before the harmonising parts, these being, in fact, formed by it during the development of the embryo. The germ is "potentially" the whole animal; during the development of the germ, the essential parts which constitute the "actual" whole are produced. The development of the separate parts out of the simple mass is observable in the incubated egg. We are not to suppose, however, that the germ is the miniature of the future being with all its organs, as Bonnet and Haller believed; it is merely "*potentially*" this being, with the specific vital force of which it is endued, and which it becomes "*actually*" by development, and by the production of the organs essential to the active state of the "*actual*" being. For the germ itself is formed merely of amorphous matter, and a high magnifying power is not necessary to distinguish the earliest rudiments of the separate organs; on the contrary, these are from their first appearance distinct and pretty large, but simple; so that the later-complicated state of a particular organ can be seen to arise by transformation from its simple rudiment. These remarks are now no longer mere opinions, but facts; and nothing is more distinct than the development of glands from the intestinal tube, and of the intestinal tube itself from a portion of the germinal membrane.

The creative organic force is not identical with the mind.—If Ernst Stahl had been acquainted with the above facts, he would have been still more confirmed in his famous theory, that the *rational soul* itself is the "*primum movens*" of organisation; that it is the ultimate and sole cause of organic activity; that the soul constructs and maintains the organisation of its body in adaptation to the laws of its intended actions; and that by its organic operations the cure of diseases is effected. Stahl's contemporaries and followers have partly misunderstood this great man, in believing that, according to his view, the soul, which forms mental conceptions, also conducts with consciousness, and designedly, the organisation of the body. The *soul* (*anima*) spoken of by Stahl is the organising power or principle which manifests itself in conformity with a rational law. But Stahl has gone too far in placing the manifestations of soul, combined with consciousness, on a level with the organising principle; the operations of which, though in accordance with design, obey a blind necessity. The organising principle, which according to an eternal law creates the different essential organs of the body, and animates them, is not itself seated in one particular organ. It continues in operation up to the time of birth in anencephalous monsters: it modifies the already existing nervous system, as well as all the other organs in the larvæ of insects, during their transformation, causing the disappearance of several of the ganglia of the nervous cord, and the coalescence of others. By its operation during the transformation of the tadpole to the frog, the spinal marrow is shortened in proportion as the tail becomes atrophied, and the nerves of the extremities are formed. This principle, thus acting conformably to design, but without consciousness, is also manifested in the phenomena of instinct. There is great beauty and truth in the saying of Cuvier, that animals acting from instinct are, as it were, possessed by an innate idea, by a dream. But that which excites this dream can be nothing else than the organising principle, the "ultimate cause" of the being.

The existence of the organic principle in the germ, and its apparent independence of any special organ in the adult, as well as the fact that it is manifested in plants, in which both nervous system and consciousness are wanting, prove that this principle cannot be compared with mental consciousness, which is an after product of development, and has its seat in one particular organ. Mind can generate no organic products, it can merely form conceptions; our ideas of the organised being are mere conscious conceptions of the mind. The formative or organising principle, on the contrary, is a creative power modifying matter, blindly and unconsciously, according to the laws of adaptation.

Origin of genera and species.—Organism, or the organised state, is the result of the union of the organic creative power and organic matter. Whether the two have ever been separate, whether the creative archetypes, the *eternal ideas* of Plato, as he taught in his "Timæus," have at some former period been infused into matter, and from that time forward been perpetuated in each animal and plant, is not an object of science, but of the fables and traditions which cannot be proved, and which distinctly indicate to us the limits of our mere consciousness. All that we know is, that each form of animal or plant is continued unchanged in its products, and that, in a roughly calculated number of many thousand species of animals and plants, there are no true transitions of one species to another, or of one genus to another. Each family of plants and animals, each genus, and each species, is connected with certain physical conditions of its existence, with a certain temperature, and with determinate physico-geographical relations, for which it is, as it were, created. In this endless variety of creatures, in this regularity of the natural classes, families, genera, and species, is manifested one common creative principle, on which life generally throughout the world depends. But all these varieties of organism, all these animals, which may be regarded as so many modes in which the surrounding world may be enjoyed by means of sensation and reaction, are, from the moment of their creation, independent. The species perishes when the productive individuals are all destroyed; the genus is no longer capable of generating the species, nor the family of restoring the genus. In the course of the earth's history, species of animals have perished by the revolutions of its surface, and have been buried in the ruins; these belong partly to extinct genera, partly to genera still existing.

The study of the successive strata of the earth, in which the remains of organic beings occur, seems to prove that the beings, which have thus left their remains on the earth, have not all existed at the same time, but that the simplest creatures have first inhabited the earth; while the remains of the higher animals, and particularly those of man, are not met with except in the most superficial of the deposits which contain organic remains. But no fact justifies us in speculations concerning the primitive, or subsequent origin of living beings; no fact indicates the possibility of explaining all these varieties by transformation, for all creatures maintain unchanged the forms which they originally received.

Nature of the organic force.—The unity resulting from the combination of the organising force with organic matter could be better conceived, if it were possible to prove that the organising force and the phenomena of life are the result, manifestation, or property of a certain combination of elements. The difference of animate or inanimate organic matter would then consist, in that state of combination of the elements, which is necessary to life, having in the latter undergone some change. Reil has stated this bold theory in his famous treatise on the "vital energy,"[*] which some physiologists,—Rudolphi, for example,—regard as a masterpiece, on which the principles of physiology must be founded.

Reil refers organic phenomena to original difference in the composition and form of organic bodies. Differences in composition and form are, according to his theory, the cause of all the variety in organised bodies, and in their endowments. But if these two principles be admitted, still the problem remains unsolved; it may still be asked, how the elementary combination acquired its form, and how the form acquired its elementary combination. Into the composition of the organic matter of the living body there must enter an unknown (according to Reil's theory, subtile material) principle, or the organic matter must maintain its properties by the operation of some unknown forces. Whether this principle is to be regarded as an imponderable matter, or as a force or energy, is just as uncertain as the same question is in reference to several important phenomena in physics; physiology in this case is not behind the other natural sciences, for the properties of this principle, as displayed in the functions of the nerves, are nearly as well known as those of light, caloric, and electricity, in physics.

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[*] Reil, Archiv. für Physiologie, Bd. i.

At all events, the mobility of the organic principle is certain: its motion is evident in innumerable vital phenomena. Parts frozen, stiff, and deprived of sensation and motion, are observed gradually to recover animation, which extends into them from the borders of the living parts. This passage of the vital principle from one part to another, is still more manifest on the removal of pressure from a nerve, after that state has been produced in which the limb is said to be "asleep." The fibrin effused in inflammation on the surface of an organ, is observed to become endowed with life and organisation. This same organic principle exerts its influence even beyond the surface of an organ, as is shown by the changes produced in the animal matter contained in the vessels, for instance, in the lymph and chyle, which latter fluid during its progress through the lacteals acquires new properties: by the coats of the blood-vessels, again, the organic principle exerts an influence on the blood, in maintaining its fluidity; for, out of the vessels the blood coagulates under almost all circumstances, unless it has undergone some chemical change. Lastly, I may with Autenrieth adduce that property of animal tissues, by virtue of which vital energy is at one time withdrawn from them, and then again imparted to them, and is often quickly accumulated in one organ. I do not think, with Hunter, that it is the influence of the vital energy which in an unincubated egg preserves the yolk and white from putrefaction; but it is certain, that an extravasated, enclosed, or morbidly collected fluid, even morbid animal matter, as pus, is preserved from putrefaction longer in the living body than out of it; which does not arise merely from the exclusion of air, since, when the vital powers are low, blood and pus rapidly undergo decomposition even in the body.* From all these facts the existence of a force which is often rapid in its action, and is capable of extending from one part to another, or of an imponderable matter, is evident;

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* Autenrieth, Physiologie, i.

nevertheless we are by no means justified in regarding it as identical with the known imponderable matters, or general physical forces,—caloric, light, and electricity, a resemblance to which is disproved by a close investigation. The researches on the so-called animal magnetism at first promised to throw some light on this enigmatical principle, or imponderable matter. It was thought that, by one person laying his hand upon, or passing it along the surface of another, and by other procedures, remarkable effects were produced, arising from the overflow of the animal magnetic fluid; some indeed have imagined that by certain operations they could produce accumulation of this hypothetic fluid. These tales, however, are a lamentable tissue of falsehood, deception, and credulity; and from them we have only learned how incapable most medical men are of instituting an experimental investigation, how little idea they have of a logical criticism, which in other natural sciences has become a universal method. There is no single fact relating to this doctrine which is free from doubt, except the certainty of endless deceptions; and in the practice of medicine there is also no fact which can be connected with these wonders, except the often repeated, but still unconfirmed accounts of the cure of paralysis by investing the limbs with the bodies of animals just killed, and the willingly credited fables of the restoration of youth to the old and diseased, by their being in the proximity and exposed to the exhalation of healthy children, and *vice versâ*.

We have thus seen that organic bodies consist of matters which present a peculiar combination of their component elements—a combination of three, four, or more to form one compound, which is observed only in organic bodies, and in them only during life. Organised bodies moreover are constituted of organs,—that is, of essential members of one whole,—each member having a separate function, and each deriving its existence from the whole: and they not merely consist of these organs, but by virtue of an innate power they form them within themselves. Life, therefore, is not simply the result of the harmony and reciprocal action of these parts; but it is first manifested in a principle, or imponderable matter which is in action in the substance of the germ, enters into the composition of the matter of this germ, and imparts to organic combinations properties which cease at death.

Conditions necessary for the manifestation of life.—Vital stimuli.—The action of the vital or organic force, is, however, not independent of certain conditions. The necessary elementary combination and the vital principle itself may be present, and yet not manifest themselves by the phenomena of life. This quiescent state of the vital principle, as it is seen in the impregnated germ of the egg before incubation, or in the seeds of plants before germination, must not be confounded with the state of death; it is also not life, but a specific state of "capability of living." Life itself, namely, the manifestation of the organic or vital force, begins under the influence of certain necessary conditions: these are warmth, atmospheric air (in ova which are hatched in water, the air diffused through the water), and the supply of moist nutritive matters,—that is to say, of nutriment and water; and these conditions do not cease to be necessary for the continued manifestation of life.

The ova of animals and plants remain in the state of "germ" only so long as they are maintained perfectly quiescent and beyond the influence of external agencies; they remain capable of development, and retain the creative force of the germ, but this force is in a quiescent state. The ova of animals will retain for a long period their capability of development, if withdrawn from the influence of the atmosphere and of caloric. Thus the productive power of the germ is preserved in the ova of many insects through the winter, and the ova of insects of transatlantic countries are hatched in the botanic gardens of Europe, an instance of which has fallen under my own observation. In the same way the germinating power of the seeds of many phanerogamic plants is said to be preserved under water for twenty years, and in the ground beyond the influence of the atmospheric air for one hundred years.* Treviranus adduces the observations of Van Swieten that the seeds of the mimosa have germinated at the end of twenty years, and beans after two hundred years; and he cites another observation, according to which an onion taken from the hand of an Egyptian mummy, perhaps two thousand years old, was made to grow.† As soon, however, as it is subjected to the external influences above-mentioned, the germ, if capable of development, becomes developed, or it undergoes putrefaction; while the already developed organism, when the conditions necessary for its further growth fail, either falls into a state of apparent death, as in hybernation, or it dies. The quiescent vital force of the germ, therefore, requires no external stimuli for the maintenance of its passive existence; but these stimuli are very necessary for the developed and active life.

Action of the vital stimuli.—The external conditions which are necessary to life,—caloric, water, atmospheric air, and nutriment, at the same time that they maintain life, induce constant changes in the composition of the organised body; themselves combining with the body, while certain old components are again decomposed and cast off. These external agencies have been called *vital stimuli;* they must, however, be carefully distinguished from many other accidental stimuli which are not essential to life; and it must always be remembered, that these vital stimuli produce the phenomena of life by effecting material changes, by producing an interchange of ponderable and imponderable matters. The essential combination of elements in the fluids, for example in the blood, is by their agency constantly maintained, and the blood having undergone the necessary change by the action of the vital stimuli, in its turn stimulates all the organs of the body. It produces in them, by the interchange of ponderable and imponderable matters, certain organic changes of composition, essential to the manifestation of life; the old components of the organs being at the same time in part decomposed and cast off. In animals, the nerves also effect important "material" changes in the organs; and their active force, probably an imponderable agent, is an important *internal vital stimulus.* The property of organised bodies, of undergoing constantly, by the action of the vital stimuli, certain modifications in the combination of their elements necessary to the manifestation of life, has been termed *incitabilitas, excitability* (Reitzbarkeit). Stimuli may be regarded as the external force which sets in motion the wheels of the whole machine; and although the comparison of the animal body with a machine may not be very apt, yet the organic principle, which in the organised body creates the mechanism necessary to life, is incapable of activity without this external impulse, that is to say, without the constant material changes effected by the aid of the external vital stimuli. Richerand has not unaptly compared the manifestation of life with the phenomena of combustion and flame, which endure only so long as the combinations and decompositions essential to combustion take place: by the union of oxygen with the burning body, caloric is developed; and so long as oxygen and combustible matter are supplied, the phenomena of combustion continue. I am very far from making life dependent on a kind of combustion; I merely say, that in both, certain essential combinations and decompositions are constantly going on, which in the one produce the phenomena of combustion and light, in the other those of life; that vital stimuli are for the organised body, what the oxygen of the atmosphere and the combustible matter are for the phenomena of combustion; in which case, however, the oxygen is not called the stimulus of the flame. I must add, that the name stimulus—vital stimulus—gives an empty and indeed false notion, unless the material changes—the constant new combinations and decompositions of ponderable and imponderable matters—induced by it be at the same time kept in mind. It is, however, necessary always to recollect, that although inorganic substances come into play in the material changes effected by vital stimuli, binary compounds are not generated for the organism, but only cast off, like the carbonic acid in respiration, as the result of the decomposition of the old matter; while the oxygen, which in the process of respiration partly enters into combination with the blood, produces a certain change in this fluid, which in its turn must give rise, in the organs endowed with the vital principle, to "material" changes, very different from those presented to us in bodies not endowed with life.

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* Ann. d. Sc. Nat. v. p. 380.

† Treviranus, Erschein. u. Gesetz des Organ. Lebens, p. 47.

These general essentials of life, the *vital stimuli,* or renovating (integrirende) stimuli, are common to plants and animals. For plants, *light* is also an indispensable vivifying stimulus; for animals, although the want of its influence renders the body scrofulous and rickety, it is not immediately necessary, as is proved by the habits of many animals, particularly the Entozoa; and its absence is only so far injurious as it modifies the other essential vital stimuli. As essential for animal life, there must be not merely the assumption of new matter, but more especially of matter already organised. Plants, again, take up as nutriment organised matters partly converted into binary compounds, and change these binary into ternary compounds. The necessity of new matter, caloric, water, and atmospheric air for the development, subsistence, and growth of organised bodies, is absolute.

A great error has been committed in classing the *vivifying stimuli* with other stimuli, which do not really contribute to the composition of organic bodies, and do not renovate their powers. A mechanical stimulus, which modifies the condition of a membrane endowed with sensibility,—for example, pressure,—excites, it is true, a vital phenomenon—sensation, but does not vivify, does not invigorate the organic forces; while, on the contrary, the essential vital stimuli really contribute to the formation of organic matter. *Nutriment*, in the first place, is not merely a stimulus of the organic body; it is itself susceptible of life, it is a stimulus which vivifies, and can itself receive vitality. Man, in the healthy state, can scarcely dispense with food longer than a week without fatal consequences; the more highly organised brutes do not live many weeks without it; while reptiles, on the contrary, (especially serpents and chelonians,) have been known to fast for months. *Water*, whether it enters as such into the composition of the organic matters, or contributes its elements to their composition, is also absolutely essential, in its uncombined state, to the manifestation of life; since the animal tissues, unless they are moist with water, are incapable of living. *Atmospheric air* is so essential for the manifestation of vital phenomena, that, in the higher animals, life does not subsist a moment without respiration, without the changes in the blood effected by respiration, and without the influence of blood, thus changed, upon the organs. The supply of nutriment, and the assumption of new matter from the blood by the organs, may be suspended for a considerable time, particularly in reptiles; but this other change, which the blood effects in the organs by virtue of its aeration in the lungs, can be omitted in reptiles but for a short time; in man, only for a few seconds. *Caloric*, lastly, which is especially important at the time when the animal system is itself yet unable to generate any heat, but is indispensable for all organic beings, plants, and animals, seems also to enter into the composition of the organic system. The organic processes require in every animal and plant a certain temperature; and it is also known, that in chemical processes among binary compounds, not only is a certain temperature required, but a determinate quantity of caloric becomes latent, or is absorbed for the formation of new products. Under the influence of the vital stimuli,—nutriment, water, air and caloric,—the organic being is developed spontaneously from the germ, while the organic matter present in it is constantly undergoing decomposition; and, thus the phenomena of life are themselves the results of the constant union of new and separation of old elements of the organised matter, and of the consequent changes in its composition. Whether electricity also is necessary to the development of life is at present quite uncertain.

There is, however, an evident *difference in the degree in which living beings are dependent on different vital stimuli.* Dr. W. F. Edwards has observed, that newly born warm-blooded animals have most need of external warmth, and cannot live without it; while they can live under water, without breathing, much longer than adult animals. The time that they can remain in the water is longer in proportion as the temperature of the water rises from 32° to 68° Fahr.; remains the same when the water is between 68° and 86° Fahr.; and becomes shorter between 86° and 104° Fahr.[*] The adult animal has, according to the vital relations of its species and genus, a certain temperature, and consequently a certain geographical tract, assigned to it in which to live.

The duration of excitability without the application of vital stimuli, is generally in the inverse ratio of the perfection of the organisation. The simplest animals can longest dispense with these stimuli. Mollusca and insects, as well as the scorpion, have been kept for months without food.[†] Serpents and tortoises also live for months without food, while man in the healthy state can scarcely survive a week. Several insects will live for days in mephitic gases; the larvæ of the œstrus, for example, according to the experiments of Van der Kolk, live for a long period in irrespirable gases. Molluscous animals have been kept during twenty-four hours under the air-pump. Reptiles, and amphibia also, live a very long time without respiring; in water deprived of its air they survive some few hours, according to Spallanzani and Edwards, and in water still containing air, from ten to twenty hours: frogs, the lungs of which I had extirpated, lived thirty hours. The numerous accounts, however, of toads, &c. having been found living in blocks of marble, and in trees, are to be regarded as instances of deception and credulity; for, although Herissaut and Edwards kept such animals alive for some little time enclosed in gypsum, the latter observer is convinced that gypsum is permeable to atmospheric air; for, when the reptiles were surrounded both by gypsum and mercury, they died as quickly as if under water.[‡]

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[*] Edwards, De l'influence des agens physiques sur la vie. Froriep's Notiz. 150, 151. See also Legallois, Exper. sur le principe de la vie.

[†] See my paper on the Scorpion, in Meckel's Archiv. 1828.

[‡] Edwards, in Meckel's Archiv. iii. 617.

The greater complication of the organisation increases the state of dependence of the organs on each other. Simply organised animals therefore live longer after injuries, than animals higher in the scale. Revival from the state of apparent death, or asphyxia, is much more easy in the lower animals. Spallanzani and Fontana saw wheel-animalcules, which had been desiccated, recover the appearance of life on being moistened with water. Ehrenberg, however, denies that this could occur. Steinbuch and Bauer have observed the same fact with regard to the Vibriones of diseased wheat and of an Agrostis; these revived when the grain was moistened, after an interval of years. After the most severe injuries, reptiles present signs of life for a long time; and the long persistence of irritability in the muscles and nerves of these animals is well known. The signs of life continue for a longer period in young animals also, probably on account of the greater simplicity of their structure. In the embryos of rabbits, I have seen muscular irritability continue longer after death than in adult rabbits; and a fœtal rabbit removed from the uterus, retained its life for fifteen minutes under the air-pump. On this point, Legallois has made some interesting experiments: he found, that, on killing rabbits by immersion in water, excision of the heart, or opening the thorax, on the first, fifth, tenth, and so on every fifth day until the thirtieth day after birth, that the duration of sensibility was less every fifth day, so that, while on the first day it continued fifteen minutes, on the thirtieth day it endured only two minutes and a half. Legallois observed the same relation with regard to the persistence of the circulation after the spinal cord was destroyed, and the head cut off. All these facts are fully explained by the law, that the more developed the individual parts of a whole are, the more dependent they must be one upon the other.

Organised bodies are subject to death.—While life is continued, with an appearance of immortality, from one individual to another, the individuals themselves perish: but if *all* the individuals of a species are destroyed, the species itself, whether of animals or plants, becomes extinct, as the history of the earth proves. The *vital* or *organic force* flows, as it were, in a stream from the producing parts into those ever newly produced, while the old parts perish. This is well described by Autenrieth:—"Those organised bodies only," he says, "which constantly strike fresh roots,—as the creeping plants, for example, by means of runners, or, as many trees, by means of descending branches,—do not die. In all these cases the new sprout forms, at one period, a part of the old individual, at the same time that it is a new and independent being. But even in these plants the old stem always perishes, and the *vital force* continues active only in the new offset, which in its turn continues to extend itself on the one side, while it dies on the other. What here takes place connectedly,—namely, the decay on the one side, and the formation of a new living body on the other,—is effected in an interrupted manner in man and the more perfect animals. The young is separated from the parent as a new living body, before the old being perishes: and the original *individual* dies, while the *species* seems to be immortal."*

Cause of death.—Why organised bodies perish, and why the organic force is transferred from the producing parts of organic beings to the young living products, while the old producing parts perish, is one of the most difficult problems of general physiology. We cannot solve it, but can only describe its successive phenomena. It would not be sufficient to say that inorganic influences gradually destroy life; for in that case the vital force would begin to diminish from the very commencement of existence; and it is well known that at the time of virility, the vital force is in such a state of perfection that it multiplies itself by the formation of germs. There must then be some other more occult cause, which induces the death of the individuals, while it insures the propagation of the vital force from one individual to another, and in this way secures it from perishing. It might be asserted, that the increasing fragility of organic bodies in old age arises from the increasing accumulation in them of certain products of the decomposition of the organic substance, the chemical affinity of which products at last balances the vital or organic force; but in that case, also, the vital force must diminish from the very commencement of life. Dutrochet supposes old age to depend on an increasing accumulation of oxygen in the animal body, but there is no proof of such accumulation taking place. All that can be done, therefore, is to show the connection of these phenomena with development.(*a*)

Why organic matter perishes.—The cause of the constant destruction of the matter of organic bodies during life, and of the necessity for its being replaced by new organic matter, is the second point to be investigated, and which is embarrassed by the same difficulties as the preceding one.

It is most consonant with facts to suppose, that the matter assimilated to an organised body becomes endowed with the organising power at the moment that it is organised. The organising force itself is in many simple organic beings divisible, by division of the organised matter. We are thus led to the very opposite conclusion to that of M. Sniadecki.† He maintains that the matter loses its capacity for life in proportion as it is endowed with life. We say, matter becomes vivified in proportion as it has experienced the vivifying force; it acquires the power of imparting life to other matter in proportion as it is itself vivified; and it exercises this power while acted on by certain *vital stimuli,* which, while they unite with the organised tissues, cause the separation and excretion of other substances. Certain *vital stimuli* entering the blood, as in the process of respiration, and then exerting their influence on the organised tissues, cause the affinity between certain elements of the organised matter and the blood to become greater than that between the different elements of the organised matter itself. The vivification by vital stimuli, and the consequent separation of effete material, render the organised matter capable of receiving nutriment; but, in proportion as a portion of new matter has life imparted to it, it acquires the faculty of giving life and organisation to other matters: it does not become excrementitious; on the contrary, it participates in the organising force of the original body.

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* Autenreith, Physiol. i. 112.

(*a*) The reasoning on this point is so much in a circle, that its omission will be no loss to the student who craves facts rather than speculations.

† Theorie der organischen Wesen, aus dem Polnischen. Nürnberg, 1821.

The cause why organic substances are being constantly decomposed and cast off from the animal body, might at first sight be thought to lie in the following circumstance:—In the conversion of the food into matters proper for the nutrition of the body, some substances, from containing an excess of useless elements, must be necessarily ejected again. Thus plants, in forming ternary vegetable compounds from carbonic acid and water, give out their superfluous oxygen. In animals, the only excrementitious matters of any consequence, which are quite useless in the organic system, are carbonic acid and the urine. The excretions of animals, it is true, nearly equal in quantity the matter taken into the body; but they are only in part entirely useless excreta: many are destined for particular purposes, or, as is the case with the mucus of the intestines and perhaps also the bile, are evacuated accidentally with other excreta. The fæces, again, consist partly of substances taken as food; whereas the urine and carbonic acid are separated from organised tissues, and are perfectly useless to the system. The urine certainly varies in its composition according to the nature of the food taken, and therefore evidently contains useless components of the yet unorganised food. But its essential composition remains unaltered in animals which live without food even for months, as many reptiles, serpents, and tortoises will do. Urea has been found in the blood of dogs killed ten days after the secretion of urine had been arrested by ligature of the nerves of the kidneys; even though, for several days before the operation, the animal had been fed only on substances perfectly free from nitrogen. The urine must, therefore, be a means of carrying out of the system parts of the organised components which have become useless; and it is evident that the vital actions themselves are attended with decomposition of organic matter. Thus even the pupæ of insects at the period of their transformation, when they take no nourishment, afford excrementitious matter by means of the Malpighian vessels; and Wurzer, Brugnatelli, and M. Chevreul have shown us that these vessels secrete lithic acid. The embryo of the higher animals, also, forms a peculiar excretion by means of the Wolffian bodies, even before the kidneys have assumed their proper function. It is remarkable that urea and lithic acid are excreted by many invertebrate animals as well as by the vertebrate; thus, insects, as we have said, secrete lithic acid by the Malpighian vessels, and M. Jacobson has discovered the same substance in a special excretory organ in molluscous animals. We have not the most distant conception of the cause which renders the reciprocal action of the atmospheric air with the living body so necessary to life; but the hypothesis, that respiration supplies the elements continually required for the formation of animal matter, or removes the elements superfluous to this compound, is refuted by the facts that most animals take the animal matter ready formed, and that reptiles continue to respire, to consume the oxygen of the air, and to exhale carbonic acid, even although they may take no food for months.

The excretions which are being constantly formed by the vital process even without food being taken; namely, carbonic acid, urea and lithic acid, are incapable of nourishing other animals. Carbonic acid is a binary compound formed by the decomposition of animal matter: urea is very analogous to a binary compound, and is perhaps really one; at all events, Woehler has shown that it is produced from cyanite of ammonia with extreme ease. As these excretions are constant, even when the supply of nutriment is stopped, it necessarily follows that a constant decomposition of the substance of the body is essentially connected with life. It cannot indeed be otherwise, since it has been shown that the vital force is manifested in an animal only while certain vital stimuli produce in the living tissues constant changes in the combination of the elements, of which the phenomena of life are merely the external signs, just as flame is the appearance resulting from the changes effected in combustion. The impulse to these changes is given by respiration; the blood, undergoing a constant change by the respiratory process, in its turn effects constant changes of composition in the organs to which it is distributed: from the former components of the tissues are formed the general products of decomposition,—carbonic acid, and the substances so rich in nitrogen which are found in the urine, urea, and lithic acid; and this decomposition of the materials of the body, which constantly attends the vital process, in its turn renders necessary the supply of new nutritive matters, which are subjected to the organising force. An organised part presents vital phenomena, and organises new matter only while it is subject to the constant action of organic affinity between the blood and the components of its tissues; by which action decomposition of a part of the organic matter is induced, while the place of this material of the tissues is again supplied by the action of the organic force upon the nutritive matters circulating in the blood.

Sources of new organised matter and vital force.—The nutriment of animals consists of organic matters, animal and vegetable; the nutriment of plants consists partly of vegetable and animal matters not wholly decomposed, and partly of binary compounds, namely, carbonic acid and water. It has been imagined that plants can nourish themselves from carbonic acid and water alone; the experiments of Hassenfratz, M. de Saussure, Giobert, and Link, have proved however that plants under these circumstances, if they grow at all, do so very imperfectly, and seldom flower and bear fruit.* It appears, therefore, that it is only when they are at the same time nourished by organic compounds in solution, which have not wholly undergone decomposition, that plants generate organic matter from binary compounds.

The power of generating organic from mineral compounds cannot, however, be entirely denied to plants; for, were it not for this power, the vegetable and animal kingdoms would soon perish. The unceasing destruction of organic bodies presupposes the formation by plants of new organic matter from binary compounds and elementary substances.

Now, by the growth and propagation of organised bodies, the organic force seems to be multiplied; for, from one being many others are produced, and from these in their turn many more; while, on the other hand, with the death of organised bodies the organic force also seems to perish. But the organic force is not merely transmitted from one individual to another,—on the contrary, a plant, after producing yearly the germs of very many productive individuals, may still remain capable of the same production. Hence the source of the increase of the organic or vital force would likewise seem to lie in the organisation of new matter; and, if this be admitted, we must suppose that plants, while they form new organic matter from inorganic substances under the influence of light and caloric, are also endowed with the power of increasing the organic force from unknown external sources, and that animals also in their turn generate the organic force from their nutriment under the influence of the vital stimuli, and distribute it to the germs during propagation. Whether, during life, the organic force, as well as the organic matter, is constantly suffering destruction, is quite unknown. Thus much, however, seems certain, that, at the death of organic bodies, the vital force is resolved into its general natural causes, from which it appears to be generated anew by plants. If this increase of the vital principle in existing organised bodies from unknown sources in the external world be rejected, the apparently endless multiplication of the vital force in the processes of growth and propagation, must be regarded as a mere evolution of germs encased one within another, or it must be admitted that the division of the organic force which takes place in propagation does not weaken its intensity; a supposition which appears absurd. But the fact would still remain, that, by the death of organised bodies, organic force is constantly becoming inert, or resolved into its general physical causes.

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* Tiedemann, Physiolog. i. 218. Translation, p. 83.

III. OF THE ORGANISM AND LIFE OF ANIMALS.

Differences between plants and animals.—Development, growth, excitability, propagation, and decay, are the general phenomena and properties of all organised bodies, and are the results of organisation; but there are other properties peculiar to animals, which may therefore be termed *animal* in contradistinction to the general *organic* properties. *Sensation and voluntary motion* are the remarkable *animal* properties.

Plants, it is true, are not wholly without *motion:* for their organisation is attended with internal movements, as in the circulation of the sap; their turning spontaneously towards the light, the extending of their roots in the direction of the most nutritious soil. Some plants climb along the surface of bodies which offer them means of attachment, and their stamens incline towards the pistil at the time of impregnation. Many indeed, particularly those of the genus Mimosa, possess in their leafstalks a power of motion which can be excited by various irritants, whether mechanical, galvanic, or chemical—such as alcohol, mineral acids, æther, and ammonia,—as well as by change of temperature or light; thus affording another instance of the general law, that the specific excitable properties of organic bodies do not vary in the mode of their manifestation according to the nature of the stimulus which excites them, but are manifested, each in its peculiar manner, on the application of the most different stimuli.* In the *Hedysarum gyrans* there is, besides the general influence of light on the motion of the larger middle leaflet, an incessant rising and falling of the two lateral leaflets, independent of external stimuli; and some of the lower vegetables—the Oscillatoria, for example,—present a constant vibratory motion. The twining of certain plants is supposed by Palm† to be dependent on their mode of growth causing the extremity of the branches to describe circles, and thus enabling them to lay hold on near objects; but, however this may be, the fact that the Cuscuta twines only around living plants, seems to show that, in it, this motion is in some measure dependent on organic attraction; and the motions of stamens and leafstalks have too much resemblance to the irritability of muscles, not to be compared with it.

There are then, in plants, organs which, by their movements, resemble either the muscles or the erectile parts of animals; but there is this difference, that the motions of animals are produced not merely by the direct action of a stimulus on irritable parts, but also by the internal operation of parts not endowed with motion, namely, the nerves, on those which have motion. Dutrochet, it is true, has observed that, when he directed the focus of a burning-glass on a single leaf of the Mimosa, the impression was propagated gradually to the other leaves; and he considers the false tracheæ, or ducts, to be the organs which transmit this influence. But, as Treviranus justly remarks, this is a mere hypothesis; for other observers have perceived only the local effect of concentrated light, and, besides, the shock produced by the local motion may be sufficient to excite motions throughout the whole plant.

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* Treviranus, Biologie, v. 201, 229.

† Palm, über das Winden der Pflanzen, p. 48.

Another remarkable character of a part of the motions of animals is, that they are excited, not merely in accordance with the harmonious action of the whole organism, but by the voluntary operation of a single organ, namely, the organ of the mental faculties;—they are voluntary. Irritability, again, must not be confounded with sensibility. Plants are irritable, but not sensible; the muscles also when separated from the animal body are still irritable, but they are not sensible. Plants cannot be affirmed to possess sensibility, unless they manifest consciousness. Manifestations of sensation and voluntary motion are the sole characteristic mark of the simplest animals. Compound animals have often a ramified and vegetable form, and are fixed by a stem to the ground; the individual faculties of the single polypes,—the voluntary motion of each polype,—indicate, however, that they have an animal organisation, (*organisatio animalis multiplicata,*) and by no means that of vegetables. The movements of Infusoria are free and voluntary. It would appear from the researches of Nitzsch,* that some vegetable and animal products of infusions are very closely allied to each other. Thus the *Bacillaria pectinalis,* and other species of this genus, would seem to have completely the characters of plants; while other species, again, have the characters of animals. Ehrenberg, however, seems not to admit the existence of such a relation between the two kingdoms; he remarks, also, that the active movements of Algæ should not be regarded as proofs of animal life, for he has never seen their moving sporules take the slightest solid nutriment.

The sensations and other incitements to voluntary motion,—the true animal functions, in fact,—are dependent on the *nervous system.* The organs of animals manifest as great a dependence on the nerves as plants on light. Nerves were known to exist in all vertebrated animals, but they had been discovered in a part only of the invertebrated; and the opinion was, till recently, very general, that the lower animals had no nerves, and that all the functions of sensation, motion, and digestion were performed by the same particles of their simple structure. The great divisibility of the lower animals seemed indeed to justify, in some measure, this conclusion. The nerves were not known to exist in the Infusoria, Polypifera, Ecalepha, and most of the Entozoa. But Otto had already described the nervous system of the *Strongylus gigas,* a worm of the kidney. In the round worm, the nervous cord between the two vascular trunks is very evident. Mehlis has described the nervous system of *Distoma hepaticum*, Nordmann that of the Pentastoma and Diplozoön. There is no doubt but it exists in all the intestinal worms. Tiedemann discovered the nervous system of the Echinodermata; at least, that of the Asterias. Lastly, Ehrenberg[*] has shown the existence of a complex structure in the lowest animals, the Infusoria. In the simplest infusory animalcules, Ehrenberg has discovered a mouth and compound stomach; in others, mouth, intestine, and anus.[†] In the more perfect Rototoria, and in some Infusoria, Ehrenberg has even described, and represented very distinctly, a kind of teeth in the mouth, male and female organs of generation, muscles, ligaments, a trace of vessels and nerves, and eye-dots. These eye-dots which Ehrenberg believes to be real eyes, and which he has discovered in the Medusæ and the Asterias, are of especial importance for the question of the existence of a nervous system in the simplest animals. On the head of Planariæ, in which no nervous system has hitherto been discovered, exactly the same eye-dots have been seen as exist in many Annelides which are known to have a nervous system; from which circumstance, and from the fact that the eye-dots of some Nereides are really formed of an enlargement of the optic nerve, with a cup-like covering of black pigment, it is very probable that the Planariæ also, and indeed all the lower animals which have such eye-dots, really possess optic nerves, and consequently a nervous system. It becomes indeed more and more probable that all animals, without exception, have nerves. The difficulty of distinguishing them in the Asterias, and in several Mollusca, teaches us that we must not attribute too much importance to the fact that even in larger animals, such as the Actinia and Medusa, there are no distinct traces of this system.

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* Beiträge zur infusorienkunde. Halle, 1817.

Animals are distinguished from plants, however, not merely by sensation and voluntary motion. These attributes necessarily modify the other functions which animals possess in common with plants. This is very beautifully set forth by Cuvier. Vegetables, fixed to the surface on which they grow, absorb immediately, by their roots, the nutritive particles of the fluids which permeate them; animals, on the contrary, which generally are not fixed to one spot, but either wholly change their situation, or at least, as polypedes of a solid stem, exert voluntary motion to seize their food, must have the means of carrying about with them the store of fluids necessary for their nutrition. By far the greater number have an *internal digestive cavity*, into which they introduce the matters intended for their nourishment, and from the parietes of which arise the absorbent vessels, so aptly compared by Boerhaave to true internal roots.* In some animals there is no anus, in others the existence of an intestine is doubtful. Nevertheless Mehlis states, in opposition to the common belief, that in the Tænia there is a vessel-like intestine, commencing at the narrow oral orifice and soon becoming bifurcated. A well-known narrow bifurcated canal in the Echinorhynchus is supposed to be the intestine. There is another cause than that above mentioned, for the necessity of a special cavity for the first process of assimilation in animals; the food of animals requires to be dissolved. The nutriment of plants is already in solution, and consists partly of water holding carbonic acid in solution, and partly of the dissolved organic matters of the soil, *humus*. The observations of Boussingault and Payen† have shown, that nitrogen also contributes in some important manner to the nutrition of plants; it being present in all parts of them, but in especial abundance in seeds and nascent parts. The food of animals, consisting of compounds already organised, requires to be prepared, comminuted, and dissolved; hence *digestion* is a preparatory assimilation of the food, peculiar to animals.

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[*] Organisation der Infusionsthierchen. Berlin, 1830.

[†] The accuracy of M. Ehrenberg's description of the digestive apparatus in his so-named Polygastrica, has recently been called in question. See Mr. R. Jones's Animal Kingdom, p. 57; J. Mayen in Müller's Archiv. 1839, p. 74; and Dujardin, Ann. d. Sc. Nat. 1838, Nov.; and Annals of Nat. History, May, 1839.

The *circulation* is much more simple in plants than in animals, and in them it is never performed by a special organ for the distribution of the fluid;—they have no heart. In some simple plants, there is a rotatory motion of the sap in the interior of internodia and in cells. In the higher vascular plants, Professor Schultze‡ has discovered a continuous motion of the sap, which according to him is a true circulation, ascending in one vessel, and descending in the other; the two streams, however, communicating by cross branches between the different vessels. This circulation is quite distinct from the ordinary ascent and descent of the sap. The forces on which it depends are unknown. The motion of the sap in plants, therefore, seems to be effected, in some manner at present not understood, by attraction and repulsion, exerted in the leaves on the one hand, and in the roots on the other. It is certain, however, that light exerts an attraction upon the sap, since it evidently determines the growth of the whole plant.

The circulation in animals, on the contrary, derives its impelling force, not from external influences, but from the contraction of a central organ, the heart. It is still uncertain, whether a perfect circulation is an absolute condition for animal organisation and life; at all events, in many simple animals, neither heart nor vessels have, so far, been discovered.

The tissue which exists most universally in vegetables, namely, the *cellular tissue*, one function of which is the transmission of the fluids of the plant, differs essentially from the cellular tissue of animals, in consisting of closed cells, while the cavities of the interstitial cellular tissue of animals communicate with each other. It would, however, be incorrect wholly to deny the existence of cellular tissue with closed cells in animals; for such vegetable-like cellular tissue exists in many parts; such, for example, is the adipose tissue, which in the Ruminantia is even polyhedral; the cellular tissue of the vitreous humour; and that of the chorda dorsalis of embryos, and of the cartilaginous fishes.

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* Cuvier, Anatomie compareé, t. i.

† Comptes Rendus. t. vi. viii.

‡ Ueber den Kreislauf des Saftes im Schöllkraut. Berlin, 1822.—Die Natur der lebendigen Pflanze. Berlin, 1823.—Annal. des Sc. Nat. t. xxii. pp. 75, 79.

The most remarkable similarity subsists between animals and vegetables in the process of the *development of their tissues.* The observations of Mirbel had shown that all the forms of vegetable tissue are developed from cells which at first constitute the whole mass of the tissue, but afterwards undergo various changes in their shape and size, so as to be converted into the woody fibre, spiral vessels, &c. M. Schleiden* has more recently traced the development of the vegetable tissue at a still earlier stage. The abundant gum of nascent parts of plants—such as the youngest albumen of a seed when examined by the microscope, is seen to be turbid from the presence of minute molecules. Soon larger granules are also observed in it; around these granules, by a kind of coagulation, larger bodies are formed, the "cytoblasts," in which the above-mentioned granules are still visible as nuclei. When the cytoblast has attained its full size, a small vesicle appears on it; this enlarges and becomes the cell, in which the cytoblast is for a period still visible, either attached to its wall or free in its cavity. In some cases, the cytoblast seems to be permanent. It is probable, from the observations of animal physiologists, and particularly of Schwann, that the process of development and growth of the tissues of animals is exactly the same. Nearly all the tissues have been shown to be formed from nucleated cells, previously developed in a homogeneous formative mass. The order of development of the cell and its nucleus, or cytoblast, and secondary nuclei within this, as far as it has been observed, appears also to be the same in animals as in plants. Some of the tissues of animals, like the cellular tissue of plants, retain the cellular form, while others, like the more highly developed vegetable tissues, assume different forms.

Respiration affords a very important distinctive character between animals and plants. In plants, and in the most simple animals, respiration is performed by the entire surface, but in the more perfect animals the surface is not sufficient for the necessary aeration of the fluids, and an organ is required, which in a small space shall afford an immense superficies for contact with the atmosphere. The products of respiration in the vegetable and the animal kingdoms are also different. In plants the assimilation of nutriment consists partly in the conversion of binary compounds, carbonic acid and water, into ternary compounds of the elements of these substances—into vegetable matter in fact. In this process an excess of oxygen remains, which is then exhaled by means of the leaves. The leaves, also, absorb carbonic acid from the atmosphere, as has been proved by the researches of Priestley, Scheele, Ingenhouss, Spallanzani, Sennebier, Humboldt, and De Saussure. By the action of the leaves, the carbonic acid contained in the atmosphere is decomposed; the carbon and a part of the oxygen combine with the plant, while the greatest part of the oxygen is restored to the air. During the night, and in the shade, as well as when they are in an unhealthy or fading condition, plants absorb a part of the oxygen of the atmosphere and exhale carbonic acid; but the quantity of carbonic acid thus exhaled is less than that which they ordinarily absorb during the day.* Respiration, then, in plants appears merely to serve for the correction of the assimilating process; while it also removes from the atmosphere a part of the carbonic acid formed by animals, and yields to it an abundance of oxygen. Animals, on the contrary, are nourished by organic matter only, not by inorganic matter; and into the composition of their substance enter not only carbon, oxygen, and hydrogen, but nitrogen also, which in many plants is quite wanting, and in others exists in very small quantity. It has been mentioned already that nitrogen has recently been found to exist very generally, and in considerable quantity, in plants: one source whence this nitrogen is derived would appear to be the atmosphere.† From the circumstance that a large quantity of animal matter is constantly undergoing putrefaction, and is thus converted into inorganic chemical compounds, while animals are quite incapable of generating new organic matter from simple elementary bodies or binary compounds, it is evident that plants, which have the latter power, are absolutely necessary to animals, just as animals on the other hand are indispensable for the existence of plants; for animals exhale that which plants inhale, namely, carbonic acid; and inhale that which is exhaled by plants, namely, oxygen. Hence, without the existence of the vegetable world, the atmosphere would become irrespirable for animals; while, by the reciprocal action of plants and animals, the composition of the atmosphere is preserved nearly absolutely unchanged.

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* Müller, Archiv. 1838, p. 137.

Lastly, plants, having only one mode of manifesting life, namely, by vegetation, do not require manifold organs in addition to their roots, stem, and leaves; and with the exception of the organs of fructification, present merely a repetition of perfectly similar parts, in all of which the simple relation of branches to leaves is the same; and even the sexual organs are evidently allied to the leaves, and in some cases are transformed into them. Moreover, a consequence of plants thus presenting before fructification merely a repetition of similar parts united by one stem is, that each of these parts has the power of becoming in its turn an independent living body when separated from the rest of the plant: for, besides the generation by seed, there is here a constant propagation by shoots. The seed, also, is an independent part: the only essential point in which it differs from a shoot being, that in the seed the vegetative power is great, while vegetative action is very imperfect, or even does not exist.

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* Tiedemann's Physiology, Translation, p. 118.—Gilby, Edinb. Phil. Journ. 1821, 7. Fungi seem to constitute an exception to the rest of vegetables in this respect. Marcet found that mushrooms converted the oxygen of the air into carbonic acid, both during day and in the night. See Lindley's Botany, p. 376, 3d edition.

† See the report on M. Boussingault's paper, in the Comptes Rendus, t. vi. p. 130.

In animals, on the contrary, the reciprocal action of circulation, respiration, and the nervous system, is actually necessary to life. The respiratory movements are dependent on nervous influence: but the nerves do not exert this influence unless supplied with blood which has been aerated in the lungs; and the blood again is not sent to the different organs, and therefore not to the nerves, without the contractions of the heart are performed; while the heart in its turn is dependent on the influence of arterial blood and of the nerves. The brain, heart, and lungs, therefore, may be likened to the main wheels of the animal machine, each acting on the other, and all set in motion by the change of material which takes place in respiration. The growth of animals also is not effected by an external protrusion of new parts, but generally by enlargement of the whole animal—by increase in size of each original part, internal as well as external. The compound polypiferous animals afford the only example in the animal kingdom of the mode of growth by new shoots. Most animals, and especially the more perfect, do not constitute an aggregate of similar parts united by one trunk; on the contrary, they contain parts of very different vital properties; and this circumstance renders propagation by divsion in them impossible, unless, as in the case of polypes and some Annelida,—as the Nereides and Naides,—each of the separated portions still contains the essential parts of the whole.

In the foregoing comparisons my special object has been to show how the possession of new properties by animals modifies in them even those functions which are common to them and plants.

Classification of the functions of animals.—The comparison of animals with plants suggested to the earlier physiologists their mode of arranging the functions of animals.

The functions which plants and animals appear to possess in common, have been called *organic* or *vital;* they have for their end the production and maintenance of all the separate parts in the self-existing whole. They are the manifestations of organic affinity in the operations of the organic or vital force. The functions which especially distinguish animal beings, namely, sensation, motion, thought, &c. appear to be the end of animal existence; they would characterise the animal, although it existed only a moment. The older physiologists named them *animal,* in contradistinction to the former, or the organic functions. A third series of phenomena comprehends the processes which lead to the formation of new germs in an individual, and to the separation and development of these germs; and which, consequently, have for their object the preservation of the species, while the individuals perish.

The above mode of classification has its advantages, but it may give rise to misconceptions. The force which determines the development of the germ is identical with that which is the source of the constant preservation and renovation of the individual. The primary forces of the animal body would, therefore, appear to be the vegetative, the motor, and the sensitive forces; but it is a question again whether even this is not an artificial division.

We can conceive that the essential principle of vegetable life, —the vegetative force,—may be combined in animals with other forces, namely, with the sensitive and motor, or with the nervous power, if the contractile power of the muscles is regarded as derived from the nerves, and not inherent in themselves. It may be imagined that these forces are united in the germ, and that, from the period of development, they manifest themselves in the different systems of organs. which react on each other; so that the vegetative, directed by the nervous force, reproduces and constantly preserves the organs of nervous life as well as other parts, while the nerves again give sensibility to the parts organised by the vegetative force. If, however, this theory be reconsidered, it will be seen to involve contradictions.

It is much more probable that these apparently distinct forces are merely different modes of action of one and the same "*vis essentialis*" resident in the animal, which modes of action are determined by the different composition of the organs. There is indeed an absurdity in the very idea that the nutritive force forms the nerves, and that the action of these nerves, when formed, results from a force distinct from that which formed them. The vital force creates in animals all the essential parts, and generates in them that combination of elements, the result of which is the power of motion and sensation, or the power of conveying impressions to a central part, which is also the source of the reflex actions. The organs endowed with the power of assimilating matters which are destined for the use of the indivisible whole, the organs of motion, and the parts by means of which a central organ receives impressions from all the other organs, and transmits its reflex actions, are only the different products of this first and sole principle of animal existence,—the *primum movens,* which produces and reproduces all parts of the body. The first set are the organs subservient to the renovation of the body, the second the muscles, the third the nerves. Then there are also parts which receive from the creative organic force merely the physical properties of hardness, elasticity, toughness, &c.—such are the bones, cartilages, ligaments, and tendons.

The glands, for example, by nutrition and reproduction, acquire the property of attracting certain parts of the blood, combining them anew, and separating them from that fluid. By the same process of nutrition and renovation, the muscles acquire the property of contracting on the application of certain stimuli,—a property which is the result of nutrition, not a special force or principle distinct from the organic creative force. And, in the same manner, the nerves receive as the result of nutrition alone the power of manifesting their vital phenomena. Omitting in our enumeration those parts which receive from the nutritive force merely physical properties, the endowments of the other principal systems of the animal body may be indicated as follows:—

1. *Organs which change the chemical composition of the fluids* for the purposes of the general system; such are the secreting organs, the blood-vessels and lymphatics, and the lungs. The peculiar function performed by these organs is not nutrition, for this is performed in all the organs of the body, but the change of the organic combination of the elements in fluids which are in contact with them, by the influence of organic affinity.

2. *Muscular organs*, which contract when acted upon by certain influences, their fibres becoming flexed in a zigzag form towards the spot where a change of their substance is produced, and thus shortened. Haller has named the property possessed by muscles, of contracting under the influence of mechanical, chemical, and electric stimuli, *irritability;* and the *irritability* of Haller can be ascribed to no other than muscular parts, while other structures are characterised by the phenomena of a different kind of excitability. By some writers this term of irritability has been greatly misapplied; thus they have spoken of an irritability in the nerves, as if at one time their irritability, at another their sensibility, could undergo a change. In the living body the action of the muscles is always determined by their nerves; and every cause which changes the composition of the nerves, although but slightly, produces a discharge, as it were, of the nervous force; and, as the result of this, a contraction of the muscles. Hence the study of muscular motions, and of spasmodic and paralytic affections generally, leads to the investigation of the laws which regulate the action of the nerves. Motion accompanies all changes of composition; it takes place in the processes of formation, nutrition, and secretion, and an organic affinity exerted between the blood and the tissues produces the motions which accompany *turgescence* or *erection*. Muscles are not the only parts capable of motion, but they are the only organs which move by contraction and zigzag flexure of fibres; and all parts which are able to contract in this manner, although not essentially muscles, derive this power from muscular substance, particularly muscular fibres, intermixed with their tissue; such parts are the efferent ducts of glands, which are distinctly contractile. The tissue which gives the dartos its power of motion may be supposed to contract by the inflection of its fibres, though of this we have no proof; but, after all, we may doubt that muscular fibres in all cases shorten themselves by zigzag inflection.*

3. *The nerves* are in part motor, in part sensitive. The motor nerves are those which, under the influence of changes in their condition so slight as to elude the perception of the observer, excite motions in the muscles. The sensitive nerves are those which have the faculty of communicating every change of condition which they

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* See the Chapter on the Muscular and Allied Motions.

undergo to the brain, the central organ, from which, again, certain influences are transmitted through them to all the other organs of the body. Many nerves, arising from the brain and spinal marrow, are, while in connection with these organs, voluntary exciters of motion in the muscles; while, under the influence of a change in their condition, whether the connection between them and the brain and spinal cord is still maintained or not, they may become excitors of involuntary muscular contractions. Those parts, on the contrary, which are endowed with motion, and are dependent on the sympathetic nerve, are withdrawn from the power of the will, and are only, in a certain degree, dependent on the brain and spinal marrow, through the medium of the connection of the sympathetic nerve with cerebral and spinal nerves. It is in the nerves that the mobility of the organic forces, without motion of the ponderable masses, is most manifest. Their operation is necessary for the exercise of all the functions of the body; since all parts of the system, through the medium of changes produced in the nerves, react on the brain and spinal marrow, and receive from these organs certain influences necessary for their peculiar actions.

These systems of organs are interwoven in different ways one with another. The sensibility of any part is owing solely to the nerves which enter into its composition: the organs which serve to produce chemical changes in the fluids, if contractile, are so only by virtue of the muscular fibres which they contain; and whenever there is a secretion of fluids in a part endowed with other distinctive vital properties, a peculiar tissue for the purpose always exists there; such, for example, is the case in the organs of sense, in which fluids are secreted by special tissues.

Organic attraction.—The reciprocal action of the foregoing systems of organs, and their nutrition by the blood, cannot take place without the manifestation of affinity in the ponderable and imponderable matters, together with organic attraction. A knowledge of the laws of this attraction would be of the greatest importance; but the facts relating to it with which we are acquainted, although remarkable, are very few in number; such are the attraction of the blood to parts which are capable of erection, and which are at the time in a state of excitement, and that remarkable coalescence of two germs by which in part double monsters are to be explained. Such a union of the germs could not have taken place without an attraction having been exerted between similar parts; for in almost all cases the monsters are united by their corresponding parts, face with face, snout with snout, either by the anterior or lateral surface, occiput with occiput, either by the middle or side, neck with neck, breast with breast, or merely belly with belly, or side with side, or merely buttock with buttock; the uniting parts of the two embryos, in these cases, always becoming single, while the cavities of the two are double. A single actual observation of this organic attraction between minute parts would be of the greatest importance. But all my endeavours to obtain this desideratum by experiment have been fruitless: I placed the nerve of a frog exposed and dissected out under the microscope, and watched the end of the nerve while surrounded by blood-globules; again I placed some semen of the frog with portions of the unimpregnated ovum under the microscope; but in neither case could I perceive anything like organic attraction.

Animal excitability.—The laws of the excitability of organic beings generally, have been investigated in a former section; and the relations which the vital stimuli bear to the manifestations of life have been there determined. The laws of the excitability of animals will be now more particularly set forth, although in the present state of science it is scarcely possible to throw any light upon this difficult problem, a knowledge of which is so desirable, since it is here that practical medicine has much to expect from physiology.

Whether the vital principle or organic force is the result of the combination of ponderable and imponderable matters, or itself determines and maintains the peculiar composition of organic matter, it is an ascertained fact, that under certain circumstances this force becomes strengthened in particular organs, the action of which then becomes greater and more continued; as is observed in the genital organs during pregnancy and the sexual ardour. Thus also the organic force is observed to become less in the antlers of the stag just before they fall off, and to be again increased when they are reproduced in an organised state. An accumulation of organic force in a part is accompanied by an increased afflux of blood, and a more abundant conversion of blood into organised matter. Tiedemann remarks, that while an organ is in an excited state, the chemical changes in its substance go on more rapidly, and that it therefore attracts more quickly, and in larger quantity the blood, which alone is able to render a part capable of increased vital action.* When, on the other hand, any organised part has suffered a lesion from change in its composition, in that case also if the change in the organic matter has not been too great, increased action ensues for the purpose of restoring the healthy state. Organised beings have the power of preserving in all parts the composition necessary for the life of the whole. When the composition is disturbed, the curative effect of this power is manifested. This is a necessary consequence of the law, that in organic bodies there is a constant striving to counteract chemical affinities. Hence the increased flow of blood to an injured part arises from the organic action in it being increased. The antagonism of the increased organic process, and of the commencing tendency to decomposition in the part, is seen in inflammation. Inflammation is not essentially a state of increased action, but is compounded of the phenomena of the local injury, a tendency to decomposition in the part and increased vital action striving to balance the destructive tendency. When the degree of change of composition in the animal tissues is greater, reaction does not ensue, and inflammation is not produced; such is the case in death by narcotic poisons. When inflammation does occur, the change produced by the injury may soon become so great that the organic reaction is not able to counterbalance it, and local death ensues.

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* Tiedemann, Physiologie, i. 326.

These and many other cases, even the fatigue and exhaustion which follow great exertions, show that the organic force is consumed by the exercise of the functions. This circumstance is evident even after death; for if we take two similar portions of muscle of an animal just killed, and excite in the one slight contractions with a knife, while the other is left unirritated, the first portion will lose its irritability sooner than the other, and the difference will be proportionate to the number of contractions which have been excited.* In the same way every impression of light deadens the power of vision in some degree, and an equal stimulus immediately afterwards does not produce an equal reaction; the eye requires rest.

This might be explained by supposing that a part of the organic force is exhausted in balancing the changes of composition produced by the stimulus. But exhaustion also ensues when the action of an organ is increased without any external stimulus, if the organic force is not increased at the same time. It appears, therefore, that the very action or exercise of organs produces a change in their composition. It may be that the constant change which is produced in the organic substance by the action of the arterial blood, and which is as necessary to life as the decomposition of the burning matter is to the phenomenon of combustion, is accelerated or increased by the action of the organ, while the renovation from new nutritive matter does not take place with proportionate rapidity, and can only be effected gradually during rest. At all events, the more exercise a man uses, the more active in general seems to be the decomposition of the matters in his body, and the more need has he for nutriment. But men and brutes that have died after very violent exercise, as in the instance of a stag hunted to death, undergo putrefaction much sooner than animals bled to death. Autenrieth,† who makes this remark, also adduces the fact, that a muscle taken from an animal before irritability had ceased, putrefies much sooner if stimulated to frequent contractions, than if left at rest. In the functions of the nervous system especially, rest is so necessary, that even the life of the most tranquil requires sleep, which comes on while the causes which excite the nervous system to action, namely, the external stimuli, are still in operation; the nervous system being rendered insensible to their impression, owing to the change induced in it by its state of activity.

The constant re-animation of the tissues by the general vital stimuli, ordinarily renders them capable of a proportionate exercise of their functions; but if their action is increased and accelerated, subsequent rest is necessary to restore as much power for new action as has been thus exhausted.

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* Autenrieth, Physiol. i. 63.

† Physiol. i. 115. See also Humboldt über die gereizte Muskel ünd Nervenfaser.

Generally, in a healthy state, just as much power is generated in a certain space of time as has been exhausted by the exercise of the functions; but there are cases in which the nutrition of the organ becomes gradually increased, while the state of action is either equal and regular, or alternates with rest. This is the case more especially in youth, because the affinity of the tissues for the vital stimuli seems, for reasons already stated, to be greater when the development is less complete: but, *cæteris paribus*, the power of an organ is always increased by exercise, not carried too far, and alternating with rest; while rest alone often induces weakness. This alternation of exercise and rest is the means by which a gradual increase of our strength is to be acquired. Life generally is attended with decomposition of organic matter; and in the same way, perhaps, the action of an organ is attended with decomposition of a part of its material, while another part becomes more intimately combined, so that, although an organ really loses matter by its state of action, still the same action renders it more capable of attracting new material and of strengthening itself. But when the action is repeated too frequently and violently, the renovation of material is less than the waste, and exhaustion ensues. This is the case when the vital force is consumed, or rendered inert, by increased action, more quickly than renovation can be effected. The exhaustion is so much the greater, the more numerous and the more important the parts of which the action is frequent and violent. Thus, for example, in the act of coition, nearly the whole nervous system is thrown into a state of activity, attended with consumption of vital force. The exhaustion of vital energy is also greater in proportion as the action of the organ is attended with the transfer of something from itself to another part, as seems to be the case in the action of the nerves, or with a real loss to the whole system, as in the case of increased secretions; for example, of the milk. The momentary state of inertness of the vital force after action, and its gradual restoration, are seen in parts of frogs even when separated from the body; the irritability being restored probably by the action of the blood still contained in the part, as well as by that of the air on the tissues. Thus, the repeated application of galvanism to the leg of a frog separated from the animal exhausts its irritability, which is again restored after a certain interval of rest.

If an organ is very rarely called into action, its power is not restored by rest in the same degree as when it is subjected to more frequent exercise. The eye, for example, requires rest after being in action; but by alternating exercise and rest it is strengthened. If the eye is kept long in complete rest, it will have acquired great sensibility; but the vital force will have become weaker in proportion to the time that it has been left without exercise; and a sudden strong impression of light will be sufficient even to blind an eye which has been thus kept long in darkness. Muscles lose much of their motor power from want of exercise; the power of the muscles of the ear, for instance, is lost from this cause.*

Reaction, Irritation, Stimulus or Irritant.—Thus far we have considered, but only in a general manner, the changes which the organic action and activity of animals undergoes. The operation of external influences in producing these changes will now be investigated. The external "vital stimuli" are not the only agents which give rise to vital actions; everything which disturbs the elementary composition of organs and the balance in the distribution of imponderable matters in the organic tissues, may also modify the action of the organism and of the separate organs. Such a modification when considerable is called *reaction;* the influence which produces this reaction in the organism is called *irritation;* and the cause exciting the irritation a *stimulus* or *irritant.* The reaction is always a vital phenomenon, a manifestation of an organic property of the animal system. The property of reaction, that of being excited to the manifestation of some inherent power on the application of an external influence, is not confined to organic beings, and still less to animals. Light and warmth are developed from many inorganic bodies, under certain circumstances, as, for example, by a blow. In these cases it is probable that the light and caloric existed in the bodies in a combined state, and are set free by the action of the external influence. A still better instance is afforded by elastic bodies, the minute particles of which have such an attraction for each other, that an attempt to displace a portion of them acts upon the whole; and by the power of attraction between them a *restitutio in integrum* ensues, accompanied by the phenomena of elasticity or sonorous vibrations. But no inorganic bodies are so uniform in their mode of reaction as organised bodies, which, under disturbing influences, however various, always manifest similar phenomena. The uniformity in the mode of reaction of organised bodies arises probably from their inherent fundamental property of counterbalancing disturbances in their composition, by a force which, in the healthy state of the body, is much stronger than the disturbing cause. The force which restores the balance in the composition of the tissues after such a disturbance, is identical with that which preserves all the properties of a part during the constant process of nutrition and renovation of material. The phenomenon which ensues on the restoration of the balance, is constituted partly by the change produced by the external cause, and partly by the effort exerted to restore the balance. Dutrochet† maintains that all stimulants produce the same change in the organism,—that they modify the state of oxidation of the organic matter on which they act; the stimulant, he says, acts simultaneously on the oxygen and the organic matter, causing them to unite. Ingenious as this theory is, it is at present a mere hypothesis; as is also the conclusion that Dutrochet comes to, namely, that excitability is really a state of susceptibility of oxidation.

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* Autenrieth, Physiol. i. 104.

† Froriep, Notizen, 724. Séances de l'Acad. d. Sc. Jan. 30, 1832.

Irritation of an organ must always be attended with some change in its component matter. Such a change must indeed be presumed to occur even in the effect of the stimulus of light upon the eye. Light appears to enter into the composition of many bodies, and produces chemical changes, which are evident in several chemical preparations, and even in plants, in which light causes the development of oxygen. The immediate effect which a stimulus produces, varies with the nature of the stimulus and of the body irritated; thus, it may be compression or a chemical change. But the secondary effect—the effort to counteract the former—is quite independent of the nature of the stimulus; it is not mechanical or chemical, but is a manifestation of the vital property of the organ, such as sensation of pain, or inflammation, or spasm. Caloric, electricity, and light are imparted to organised beings according to the general laws of physics; but in the "*restitutio in integrum*" there always arises, at the same time, a vital action, which differs in its kind according to the part that has undergone the change; and, until the part is restored to its natural state, the phenomena observed are compounded of the operation of the stimulus and the reaction which it has excited. Chemical substances also produce a change in organic bodies, and have a tendency to form binary compounds with their elements. If this occurs,—if the organic affinity is not able to counteract the chemical agency,—a chemical product is formed, at the same time that the life of the part is destroyed, as is observed in the case of burns, and of the application of mineral acids or a caustic alkali. But the organised structure, in the part thus acted upon by a chemical agent, while it retains its life, and on the boundaries of the part after its death, manifests the organic properties peculiar to it, such as sensation, motion, or inflammation.

Not merely, however, does the reaction of animal bodies consequent on the application of external stimuli, differ from that of inorganic bodies, in its being manifested by vital properties; but also these vital properties themselves vary according to the nature of the organ and of its composition. Thus, for example, mechanical, chemical, or electrical stimuli applied to a muscle, all produce in it the same mode of reaction, namely, motion; while all stimuli applied to a sentient nerve excite only sensation, which is very different in different nerves, even though the exciting cause be the same; and, again, it is always the same in the same nerve, though the exciting causes be different. Mechanical and electric stimuli excite, in the optic nerve, the perception of light, which is the peculiar property of that nerve, and seem to excite no pain; while pain, and not the perception of light, is the constant result of irritation of a nerve of common sensation. In the same way, mechanical and electric stimuli produce in the auditory nerve the perception of sound, and electricity excites in the olfactory nerve the sensation of smell. The anterior roots of the spinal nerves when irritated mechanically or by galvanism, give rise to no sensations,* but to muscular contractions; while the posterior roots of the same nerves, under similar circumstances, excite sensations only, and no contraction of muscles. By ascertaining the mode of reaction peculiar to all parts of the body, physiology acquires an empirical knowledge as certain as any possessed by the other natural sciences.

In quite different states of disease of the same organ, the symptoms are often very similar; for, in a state of excited action, as well as in a state of irritation with diminished power, the organ will manifest the vital properties peculiar to it. There are certain groups of cerebral symptoms, and of symptoms of cardiac disease, which occur in very different morbid conditions of the brain and heart respectively. We may here remark upon the folly of the homœopathists, who imagine that they cure disease by means of substances which produce states of the system resembling the disease; while they either do nothing whatever, or nature applies the remedies otherwise than the homœopathist imagines. The fact of two substances producing similar symptoms in an organ, does not prove that their modes of action are identical, but merely that the organ on which they act is the same. Syphilis, and the mercurial disease, may be essentially very different; and yet they so far resemble each other that certain organs are affected by both. Mineral acids and alkalies, also, are equally destructive to the organised tissues, and nevertheless no one will assert that they are "*similia.*" Mercury, by inducing a slight change in the organic matter of the body, may render it unfit for propagating the destructive progress of syphilis; and then the natural vital process, and not the mercury, effect the further cure.

The action of an organ being excited by stimulants, and every increase of action without simultaneous increase of organic force being attended with exhaustion of this force, stimulants themselves must exhaust, or, as it were, consume the organic power; and unless, like the general *vital stimuli*, they have at the same time a restorative action, a temporary cessation of the action they have themselves excited will follow, although their influence be continued. Hence the periodic character of many vital phenomena. A contractile organ, containing a matter which stimulates it mechanically or chemically, contracts. By this act of contraction the part is rendered incapable, for a moment, of again contracting with equal strength; but the excitability is gradually restored, and the stimulus, which is constant, becomes again effective; and so the contractions are repeated from time to time. This intermittent action is seen in the undulations of the iris under the influence of an equable light, in the periodic contractions of the rectum, intestines, stomach, heart, uterus, urinary bladder, and of the muscles which expel the contents of the urethra *in coitû.* The stimulus to contraction is, in many of these cases, external,—a substance contained in the cavity of the organs, such as urine, fæces, &c. It appears, however, also to be frequently internal or inherent, to be derived, for instance, from the nerves; as in the case of the heart, the rythmic contractions of which seem to be dependent on nervous influence, and are not wholly and primarily due to the periodic stimulus of the blood in its cavities; for the contractions continue when the organ is cut out from the body and empty of blood. In this case the stimulus of the blood is not replaced by that of the air, for the action continues in a vacuum.

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* Recent experiments of M. Longet and M. Magendie seem to show that the anterior roots of the spinal nerves derive some sensibility from their connection with the posterior roots. See the Chapter on the sensitive and motor roots of the spinal nerves.

A stimulus too often repeated, deadens the excitability of the organ, and renders it insensible to the same stimulus for a long time afterwards. Hence may be explained a part of the phenomena observed in the effects of habit. Many things, to the action of which after long repetition we become thus insensible, produced at first not merely the phenomena of excitement, but ultimately a durable structural change, whence alone their subsequent inefficacy can be explained.

Classification of medicinal agents.—As the modifications produced in the composition of the organised tissues, by the numerous agents and substances to the influence of which the organism is exposed, vary so indefinitely according to the nature and composition of these agents and substances; and as we are unable to determine the nature of each modification, it is impossible to bring the substances used in medicine under a good general arrangement. Viewing them generally, however, there can be but three principal modes of action, and three classes of agents.

1. *Stimulants.*—The true and most important stimuli are, as I have already shown, the vital stimuli themselves, the constant operation of which on the tissues is the sole cause of the manifestation of life, and of the increase of the vital force. The vital stimuli, namely, a certain degree of external heat, atmospheric air, water, and nutriment, not merely produce a change in the composition of the organic structures, and stimulate, by disturbing the balance in the system, but they renovate the tissues by entering, in a manner indispensable to life, into their composition. These influences, which are constantly in action, and which, while they stimulate, leave no exhaustion after them, are the only efficient means for restoring the powers of the body after sickness. There are many other stimuli which excite reaction, but which are not essentially renovating, and indeed for the most part have no restorative action on the organs; and which, except in producing symptoms or phenomena of reaction, have no vivifying influence; but, on the contrary, they are injurious in proportion to the change effected by them in the organic composition. An endless injury has been done to medicine, and many lives have been lost, through the error of confounding all agents which excite reaction in the system with those which are absolutely essential to life, and which renovate while they stimulate the organs; the false notion having been thereby induced, that, because certain stimuli feed as it were the flame of life, stimulating agents generally are

necessary to life.(*a*) There are, however, some agents, in addition to the general vital stimuli, which, under certain conditions, exert a local, vivifying, and strengthening influence, either by restoring the composition of the organ, or by so changing its composition, that the renovation by the general vital stimuli is facilitated. All this, however, depends on the state of the diseased organ; and the cases in which the so-called stimulant and tonic remedies have really their supposed effect, are very rare. On the other hand, many patients have been stimulated to death by a host of remedies which, under the circumstances of the case, or in all cases, do indeed stimulate, but produce only a tumult in the system which they fail to strengthen. Those substances which, under certain conditions, have a vivifying influence, also act, according to their composition, more especially on particular organs, and form natural groups according as their principal action is on the nervous system, for instance, or on the organs destined to effect changes in the blood. Several of these agents are imponderable matters, such as electricity, which has been used with success in paralytic affections. Caloric, that agent which is necessary in the development of the embryo, has also an eminently vivifying influence in states of disease, when other means are fruitless; for instance, in affections of the nerves and spinal cord,—paralysis, neuralgia dorsalis, and commencing tabes dorsalis; the application of heat being made in the form of moxa, and frequently repeated, even by a new moxa on the old granulating surface: the application of a single moxa is mere trifling. A much more durable impression of heat, better than moxa or the actual cautery, is produced by holding a burning candle near to the affected part for a long time, so as to cause pain; by which means all the beneficial effect of heat is obtained, without the formation of an eschar and the subsequent suppuration, which is often of no service. The mode in which the caloric acts in these cases, is not evident; moxas are beneficial in diseases of the spinal cord, only when applied close to the spine, while pain may be excited in any part of the body.

Mechanical influence by frictions acts under certain circumstances as a vivifying stimulus; it has this effect, probably, by inducing slight chemical changes in the composition of the tissues, as a consequence of which their affinity for the general vital stimuli already in the organism is increased.

On the other hand, all agents of this kind, as well medicinal substances as caloric, electricity, and mechanical influences, such as pressure, contusion, &c., may, when their action is excessive, have the very opposite of a vivifying effect, and produce such a violent change in the organic matter, that the combinations necessary to life cannot be maintained: hence these influences are special stimuli, vivifying only under certain conditions. They exert a vivifying

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(*a*) From this confounding under one head different kinds of stimuli, have arisen pernicious abuses in hygiene, the worst of which was, converting alcoholic stimuli into substances of daily use, and attributing to them the power not only of strengthening but of renovating the organs—a doctrine false in physiology and eminently destructive in practice.

influence when their action on the organic matter favours the production of the natural composition of the parts. They may, therefore, be termed *homogeneous stimuli;* while all other stimuli, which only disturb the natural composition of the body, and with it the state of the vital powers, may be termed *heterogeneous stimuli:* these have no vivifying influence, but are rather injurious to life. It must, however, be remembered that every homogeneous stimulus, when used under improper circumstances, becomes a *heterogeneous stimulus.* Stimulants then would seem to be divisible into, 1. general vital stimuli; and 2. special stimuli: and these last again into *a*, the homogeneous; and *b*, the heterogeneous. I have already mentioned that Dutrochet supposes that true stimuli act by favouring and accelerating the combination of oxygen with organic matter. It is probable, that the action, at least of several stimuli, depends on their having the property of strengthening the affinity between the organic substance and the blood, (which, by its passage through the lungs, is itself rendered a vital stimulus,) and thus of increasing and accelerating the changes produced in organic matter by the oxygen in the blood.

In cases of rapid sinking of the vital force, all our stimulant remedies are of no avail; and the greater number of them merely excite the system, and do not add to its strength.

2. *Alteratives.*—A great number of substances are important as therapeutic agents, from their producing a chemical change in the organic matter, the result of which is, not an immediate renovation of material and an increase of vital force, but a removal of that state of combination of the elements which prevented healthy, or caused diseased action. Perhaps the chemical change produced is such as to render the organ no longer sensible to a morbid stimulus; or it is such that certain apprehended destructive changes of composition are no longer possible, as in the antiphlogistic plan of treatment; or, lastly, these substances produce a change in the nutritive fluids. Such substances are alteratives. By these remedies an organ morbidly changed in composition cannot be rendered sound, as though by a chemical process; but such a slight chemical change can be produced as shall render it possible for nature to restore the healthy constitution of the part by the process of nutrition. These "alteratives," again, may be divided into two principal kinds, according as they act chiefly on the nervous system or on the other organs dependent on that system. Among those of the first kind, the most important are the so-called narcotics; those of the latter kind comprehend the numerous medicines which exert their action on diseases in other organs than those of the nervous system. These remedies, also, by removing the obstacles to cure, become indirectly vivifying or renovating stimuli, and they may themselves, by disturbing the balance in a part, produce symptoms of irritation. If used in excess, they either give rise to the injurious effects of the heterogeneous stimulants, or by inducing a sudden change of composition, annihilate the vital force, as is the case with narcotics. Since, however, such altera-

tive medicines affect, each in its own way, the composition of an organ, one alterative may, after a time, lose its influence, while the organ thus saturated, as it were, with the remedy, may still be susceptible of the influence of another. The practice of medicine affords, in innumerable cases, a confirmation of this statement. By the continued use of an alterative medicine, the composition of the organ will have suffered such a chemical change, that the same affinity for this substance no longer exists in the organism, while an affinity for another substance may still remain. Imponderable matters also are in this way alterative; thus the eye, after being long fixed on a green surface, loses gradually its sensibility for this colour, which becomes dull and grey. At the same time, however, the sensibility for the red rays is increased. So, also, a long exposure of the retina to the red rays makes it susceptible of the green. In the same way, by fixing the eye for some time on yellow, the sensibility for that colour is lost, while the perception of violet becomes more intense, and *vice versâ;* the same relation exists between blue and orange.

3. *Agents which destroy the organic composition.* (Decomposing agents.)—These are substances which, without first producing a stimulant or simply alterant effect, directly destroy the essential composition of the organised tissues. Some of the agents which are "stimulants" when they operate gently, produce by a more violent action too great a disturbance of the powers of the part; such are heat, electricity, &c. Others are "alteratives," which by an extreme degree of their action produce great changes in the composition of the tissues, forming with the organic matter combinations which the organic force is not able to counterbalance. It is in this way that the *narcotic alterants* have a destructive action; and those alterants which modify the formation of the fluids of the body, and the organic changes effected in them by different organs, —for example, the antimonial and mercurial preparations, and the mineral acids and alkalies,—have, when in a concentrated state, an equally destructive influence on the organic composition. Stimulants can produce disorganisation in two ways. Some agents are stimulants only when their action does not surpass a certain degree of intensity; and, when their action is more violent, instead of renovating the organic composition and force, or even favouring this renovation by exciting new affinities, they produce immediately an essential change of composition. In this case no irritation or reaction precedes the local or general death; the disorganisation is immediate, as in death from electricity, lightning, &c. Other stimuli, which under certain conditions have a renovating action, may have a destructive effect by exciting the action of an organ during too long a period: more force being exhausted than can be restored again in an equal space of time. This action is called over-excitement. An organ thus over excited, as, for example, the eye by light, is rendered permanently weaker. The decomposing agents are used in medicine only when it is wished really to produce destruction of a part.

of arranging diseases, therefore, is founded on the different systems of organs affected, and the types of disease established by their natural history. Physicians have always been inclined to regard inflammation as a disease with increased vital power. Certain properties of the body are increased in an inflamed part,—for example, heat;—the quantity of the blood in the capillaries is greater, but other conditions of the part are altered; while the function of the organ is interrupted, and the sensations indicate a violent lesion. The exciting cause of inflammation produces a chemical change in the composition of the affected organ: it is in this way that inflammation is produced in the practice of medicine by chemical agents. A chemical affinity, an attraction, may arise between the blood and the tissues thus chemically changed. This new affinity may be greater than that of the healthy state. But whether the increased affinity between the tissue and the blood in inflammation be merely a greater degree of the natural organic attraction, such as is observed in certain healthy phenomena, as in all those of turgescence,—or whether it is essentially different from the organic attraction, and is a newly arisen chemical affinity between the disorganised matter and the blood,—cannot with certainty be determined. But even if the increased affinity between the blood and the organic substance be really a greater degree of that reciprocal action which is constantly going on between the blood and the tissues, still inflammation is not a disease of increased vital power; for the phenomena of inflammation arise as much from the existing tendency to decomposition excited by the chemical change, as from the reaction of the tissues to oppose this destructive tendency.

The intimate reciprocity of action which exists between all parts of the organism, especially through the medium of the nervous system, produces in animal bodies a kind of balance (Statik) of the forces; whence it results, that an exciting cause of disease acting on one part, by changing the state of the ponderable and imponderable matters in it, often exerts its influence through a series of such changes on distant parts, which are most susceptible of this form of disease. The withdrawal of matters at one point prevents the accumulation of similar or different matters at another spot, on which is founded the use of evacuating means at parts of the body distant from the disease. Still more, the increase of vital action in one organ excites many others: hence the connection of the increased vital action in the genital organs with the reproduction of the antlers in the stag, and with changes in many organs in man, which changes, both in the stag and in man, are prevented by castration.(*a*) The application of renovating stimuli, also, to one part, has a vivifying influence on the whole system; reacting from the skin, for example, on the central organs of the nervous system through the medium of the nerves; whence arises the successful use of frictions and other stimulants to the skin, for the restoration of suspended animation.

(*a*) The illustration would have been more complete by the author's including the cerebellar changes in the circle of newly associated actions.

IV. OF THE PHENOMENA, OR ACTIVE PROPERTIES, COMMON TO INORGANIC AND ORGANIC BODIES.

Organic bodies participate in the general properties of ponderable matter. The laws of mechanics, statics, and hydraulics, are also applicable to them. Several of these properties, which organic matters may possess in common with inorganic substances, such as cohesion, elasticity, &c. exist, however, only while the essential composition of the part is maintained by the continued operation of the organic force; thus the elastic coat of the arteries loses its elasticity at a certain period after death, if it is allowed to putrefy. The application of the laws of mechanics, statics, and hydraulics to the actions of organic bodies is also limited, from the circumstance that the causes of motion most at work in these latter are essentially vital in their nature. The imponderables, also, namely, electricity, caloric, and light, are developed by organic bodies. It is these matters that we must here particularly consider.

1. *Development of electricity.*

Sources of electricity.—The electricity excited by friction is well known to be developed with remarkable facility from many substances of organic origin. Galvanism, or the electricity of contact, is produced not merely by the contact of heterogeneous metals, but by means of many other substances, particularly carbon and graphite, as has been shown by Humboldt and Pfaff; and even different animal substances connected by conducting bodies will produce in a less degree the same phenomena as metals of different kinds. It would, therefore, be quite erroneous to suppose that the causes of galvanism are to be sought only in the properties of different metals. Seebeck has discovered that even bars of the same metal heated to different degrees of temperature, and placed one upon the other, will become electric; and that one simple metallic bar made of a different temperature at the two ends acquires this property: so that difference of quality of the bodies coming into contact, (and thus throwing the electricity which is present in all bodies into the state of positive and negative electricity, or disturbing the balance of the electric matter,) and their connection by means of a third conducting substance, seem to be the most general conditions required for the production of galvanism. When these conditions are present, galvanic phenomena are produced in various parts of animals also. Baron von Humboldt discovered that feeble contractions are produced in the leg of a frog by touching the nerve and muscle at the same moment with a fresh portion of muscle. This is certainly one of the more rare results of galvanic experiments; but I have repeated the experiment several times, and can confirm the accuracy of the statement. Buntzen indeed formed a weak galvanic pile with alternate layers of muscle and nerve; and Prevost and Dumas state that a circle formed simply of one metal, fresh muscle, and a saline solution or blood, affects the galvanometer. If to the conductors of the galvanometer, plates of platinum are fixed, and a piece of muscle of several ounces weight is placed upon one of these plates, the conductors being then immersed in blood or a saline solution, a deviation of the magnetic needle of the instrument takes place. Or, if to one of the conductors a piece of platinum moistened with muriate of ammonia or nitric acid is attached, to the other a portion of nerve, muscle, or brain, and the two conductors are made to communicate, the same deviation of the needle is produced.* Kaemtz† has moreover shown, that dry but efficient galvanic piles can be constructed from organic substances without any concurrence of metals. Concentrated solutions of organic substances were spread upon thin paper, and with disks of this paper piles were constructed, the two layers of different substanses being separated by two thicknesses of paper; the electricity developed by these piles was tested by an electrometer (Bohnenberger's). It was by this means ascertained that

Soda	is positive electric in relation to	Mutton fat.
Yeast	. . . .	Cane sugar.
Yeast	. . . .	Common salt.
Yeast	. . . .	Sugar of milk.
Linseed oil	. . . .	Sugar.
Linseed oil	. . . .	White wax.
Starch	. . . .	Gum.
Gum	. . . .	Saloop.
Gum	. . . .	Mucus of Tragacanth.
Gum	. . . .	Seeds of Lycopodium (Bärlappsamen).
White of egg	. . . .	Gum.
White of egg	. . . .	Bullock's blood.
Bullock's blood	. . . .	Extract of Belladonna.
Bullock's blood	. . . .	Starch.

These facts being known, the phenomena to which *electric fishes* give rise appear less extraordinary, although the power in these animals of producing electric discharges exists only during life, and during an undisturbed state of the nervous influence. The electric fishes which are best known, are the electric Ray, or Torpedo, of which the species *ocellata* and *marmorata* are met with in the seas of the south of Europe; the electric Eel, *Gymnotus electricus*, which is found in several rivers of South America; and the *Silurus electricus*, or *Malapterurus electricus*, met with in the Nile and in Senegal. The *Rhinobatus electricus*, *Trichiurus electricus*, and *Tetrodon electricus*, are less known. Walsh, Fahlenberg, Gay Lussac, and Humboldt contributed most to our knowledge of these fishes.

The electric organs of these fishes consist of minute cells with membranous parietes, occupying much of the body and largely supplied with nerves; the nervus vagus being distributed to the electric organs of the torpedo, and the intercostal nerves in great number and of extreme minuteness to those of the Gymnotus and Silurus, while branches of the fifth are sent to the external parts.‡

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* Magendie, Journ. tom. iii. † Schweigger, Journ. 56, 1.

‡ Hunter in Philos. Trans. 1773, p. ii. tab. 20; and Animal Œconomy, p. 404, 15; Philad. Edit. Rudolphi in den Abhandlungen der Academie von Berlin, 1820, 1821, p. 229, tab. i. ii. and 1824.

The effects produced by the electric fishes on animals are perfectly analogous to electric discharges. The shock from the Torpedo when the fish is touched with the hand, reaches to the upper arm. The Gymnotus will attack and paralyse even horses, as has been so well described by Humboldt. Substances which are conductors or non-conductors of electricity, are equally so to the influence communicated by the Torpedo and the Gymnotus, which are the only electric fishes that have been hitherto accurately examined with reference to their electric action: a shock is propagated through a chain of several persons when those at the extremities of the chain touch the fish. Walsh, indeed, by conducting the discharge of the Gymnotus through a strip of tin foil gummed to a piece of glass and cut through in the middle, obtained sparks, which were seen by Walsh, with Pringle, Magellan, and Ingenhouss, passing at the line of the section from one half of the foil to the other.* Fahlenberg has repeated this experiment with the same result while the fish was exposed to the air.† More recently Linari and Matteuci‡ have succeeded in obtaining a spark from the Torpedo.

The electric fishes have never been observed to produce any effect on the electrometer. Dr. J. Davy was the first experimenter who obtained a decisive result; he discovered that the electric organs of the Torpedo have really an electric action on the galvanometer.§ He has also succeeded in decomposing water and in rendering needles magnetic.‖ Linari and Matteuci also have communicated the magnetic property to needles, have decomposed water, and have observed marked deviations of the galvanometer at the moment of the discharges.¶

Laws which regulate the discharges from Electric Fishes.—The power of producing the discharge is quite voluntary, and dependent on the integrity of the nerves of the electric organs. The heart may be removed, and the shocks will still be communicated for a long time; but with the destruction of the brain, or division of the nerves going to the organs, the power ceases. The destruction of the electric organ of one side does not interrupt the action of the opposite organ. All observers agree, that the electric discharge does not take place every time when the fish is touched, but depends on a voluntary power; and hence it is often necessary to irritate the fish. Moreover, it would appear that it has the power of determining the direction of the discharges; for when Humboldt and Bonpland laid hold of the fish, one by the head, the other by the tail, the shock was not always felt immediately, and both did not always receive it. Sometimes the animal struggles when teased, without giving any shock. It seems to be itself scarcely sensible of the shocks. In the electric Eel no motion is observed at the time of the discharge, and in the Torpedo there is merely a slight motion of the thoracic fins. Yet the electric fishes are very sensible to the artificial galvanic stimulus applied to wounds. No convulsive motions, however, are produced in the Gymnotus, according to Humboldt's observation, when one of these fishes forms the conducting medium of a shock from another fish.

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* Journ. de Phys. 1776, Oct. 331.

† Vetensk. Acad. Abhand. 1801, ii. p. 122.

‡ L'Institut. 167.

§ Philos. Trans. 1834, p. 2.

‖ Ibid. 1832.

¶ L'Institut. Juillet, 1836.

The electric shock is felt, if the animal is inclined to communicate it, by merely touching one surface with a single finger, as well as by applying the hand to both surfaces, dorsal and ventral. In either case it is a matter of indifference whether the person who touches the fish is isolated or not. (Humboldt.) Matteuci, on the other hand, states that the leg of a frog was, in his experiments, never thrown into contractions unless it touched the surface of the Torpedo at two points at least; but his recent observations lead him to doubt the possession by the animal of such a power of directing the discharges.

In many respects the Torpedo and Gymnotus agree; in a few they differ. Gay Lussac and Humboldt have remarked some interesting points of difference. When the Torpedo is touched even with a single finger, the discharge takes place, whether the person be isolated or not. But when he is isolated, the contact must be immediate; if the fish is touched merely with a piece of metal in the hand, no shock is felt. The Gymnotus, however, transmits its electric discharge through a bar of iron several feet in length. If a Torpedo is laid upon a very thin plate of metal, the hand which holds the plate never perceives the shock, even though the fish be irritated by another person who is isolated, and though the spasmodic movements of the thoracic fins indicate that strong discharges are taking place. But if, while it is lying on a metallic plate held as before with one hand, the Torpedo is touched on the upper surface with the other hand, a powerful shock is felt in both arms. The sensation is the same when the fish is between two metallic plates, the edges of which do not touch each other, and when the hands are placed at the same time on the two plates. But when the borders of the plates are in contact, the shock entirely ceases to be felt; the circle between the two surfaces of the electric organs is completed by the metallic plates, and the new circle formed by bringing the two hands in contact with opposite plates has no effect.

Electric fishes which are still vigorous, exert their electric power as strongly in the air as in the water. If several persons form the chain between the upper and under surfaces of the fish, the shock is not felt unless these persons have previously moistened their hands. The discharge, however, is felt by two persons who, while grasping the Torpedo with their right hands, complete the circle—not by holding each other by the left hands, but by each dipping a small bar of metal into a drop of water on an insulated body.* Dr. Davy observed that the electric discharges of a Torpedo continued after the brain of the fish was divided lengthwise; but that after the removal of the brain, no more shocks were given even when the nerves of the electric organs were irritated. In one instance, when a small portion of brain had accidentally been left in connection with the electric nerves of one side, the fish gave a shock when irritated. M. Matteuci found that the intensity of the shock diminished in proportion to the number of the nervous fibres going to the organ which he divided, and that it was no longer given when all the nerves were severed. The death of the fish produced by morphia was attended with strong electric discharges and convulsions. When the animal had ceased to give shocks even though irritated, discharges stronger than ordinary were excited by touching the part of the brain (an enlargement of the medulla oblongata) from which the nerves of the electric organs arise. All parts of the brain in front of this fourth lobe or enlargement of the medulla oblongata, may be removed without arresting the electric discharges. The cerebral hemispheres may be touched, wounded, or cut away without any discharge being excited, but irritation of the optic lobes between the cerebral hemispheres and cerebellum sometimes caused an electric discharge when the animal was vigorous.*

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* See Gay Lussac et Humboldt, Ann. de Chimie, 65, 15.—A. v. Humboldt, Reise in die Æquinoctialgegenden des neuen Continents. 3 Theil, pp. 295–324. —Treviranus, Biolog. v. 144–180.

Electric phenomena in frogs.—The electric phenomena of the electric fishes are effected by means of special organs. Whether electricity is developed in animals by ordinary vital processes is another question. Electricity exists in all bodies in a state of equilibrium, and is manifested in them when, by contact of heterogeneous bodies, it is thrown into positive and negative states; in this way it can be made evident even in living frogs. In the spring before the time of breeding, and in the latter cold part of autumn, but not in the summer, frogs evince great sensibility to the galvanic stimulus. If at these times the leg of a frog, dissected in the usual manner, is laid upon a glass plate, and the crural nerve touched with a plate of zinc held in one hand, while the experimenter touches the leg with a finger of the other hand, a strong contraction of the muscles ensues every time the circle is thus closed; if copper is used in place of zinc, the result is the same, but the contraction is not so strong. The experiment in which I excited muscular contraction, nearly in the same manner as had been done by Humboldt, by turning back the nerve towards the surface of the leg still covered with cuticle, without any intermediate conductor of metal or muscle, proves that for the simplest electric phenomenon on frogs, or separated parts of frogs, the mere contact of nerve and muscle, which at their other extremities are organically connected, is sufficient, and that the use of conductors of metal, or of fresh or putrid muscle, merely strengthens the phenomenon. It appears then, either that free electricity is generated in living bodies, and that when certain substances come into contact an overflow of this electricity takes place and produces muscular contractions, or that the mere difference in chemical properties of the nerve and muscle, produces an elastic tension, while closing the circle restores the electric equilibrium and produces the contraction.

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* Matteuci, Biblioth. Univ. xii.

Much that is fabulous has been alleged concerning the development of electricity during the vital process. The truth is, that the electric phenomena, which are manifested in animals independent of friction, are very feeble; although it does not appear possible for the various chemical changes which take place in them to occur without some development of electricity.

Free electricity in man.—All that is known concerning the development of electricity in the human subject under the influence of the vital process, is furnished by the researches of Pfaff and Ahrens.* The experiments were performed with the aid of a gold-leaf electrometer, the persons who were the subjects of them being placed upon an insulating stool. The collector-plate of a condenser, which was screwed upon the electrometer, was touched by the person, while the other plate of the condensor communicated with the earth. The results obtained are the following:—

1. As a general rule, the kind of electricity evidenced by man in the healthy state is the positive.
2. It seldom exceeds in intensity the electricity excited when copper, which communicates by a conducting substance with the earth, comes in contact with zinc.
3. Excitable persons of a sanguine temperament have more free electricity than indolent persons of a phlegmatic temperament.
4. The quantity of electricity is greater in the evening that at other periods of the day.
5. Spirituous drinks increase the quantity of electricity.
6. Women are more frequently negative electric than men, although there is no determinate rule for the greater prevalence of this kind of electricity in them. Gardini had found that women manifested negative electricity at the time of menstruation, and also during pregnancy.
7. In the winter, the bodies of persons who are very cold, at first give evidence of no electricity; but it gradually becomes manifest as warmth is restored.
8. The body, when perfectly naked, manifests the same phenomena, which are also common to all parts of it.
9. During the continuance of rheumatic affections, the electricity of the body seems to be reduced to zero, and to become manifest again as the disease subsides. It appeared to Humboldt† also, that rheumatic patients had an insulating action on the feeble current produced by a simple galvanic circle.

Do any vital actions depend on electricity?—Much has been said of the production of several vital actions, particularly those of the nerves, by the agency of electricity. But nothing of this kind has been demonstrated. Neither Person‡ nor I have ever been able to detect electric currents in the nerves.[*] Pouillet at first thought that he had perceived electric currents in needles inserted into the flesh in the operation of acupuncturation: but he has himself acknowledged his error.[†]

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* Meckel, Archiv. iii. 161.

† Humboldt, über die gereizte Muskel. und Nervenfaser, i. v. 159.

‡ Magendie, Journal de Physiol. x. 216.

In the nerves themselves Matteuci could detect no electric action; nor could he discover that the nerves affected the galvanometer, even when the current of a galvanic battery is passed through them. Hence, even if there were really electric currents in the nerves, they would not be detected by the galvanometer.[‡] Bellingeri has made some experiments on the electricity of the blood removed from the body, as well as on that of the bile, and of the urine, from which he concludes that in inflamed blood the electricity is diminished, and that blood retains its electricity long after it has been abstracted from the body.[§] But how desirable it would be to prove first the real existence of free electricity in the blood generally!

The experiments of Donné, Matteuci and others, which seemed to show that galvanic currents existed between different parts of the living body, as between the inner and outer surface of the skin, and between the liver and stomach of an animal, are now known to be inapplicable; for similar phenomena have been produced on the dead body by Weber, (*Questiones physiologicæ de Phænomenis galvano-magneticis de corpore humano observatis*, Lips. 1836.) It appears from the observations of M. Weber, that no substance in the human body is so good a conductor of galvanism as the metals; for the different parts of the human body do not conduct the galvanic influence better than substances impregnated with blood and warm saline fluids might be expected to do, namely, from ten to twenty times better than distilled water of the same temperature, which is about the conducting power of a warm saline solution. This refutes the notion of those persons who imagine that the nerves resemble the metals in being excellent conductors of electricity. The epidermis especially, when dry, is a very bad conductor, being fifty times inferior to the rest of the body in this respect.

Galvanism is generated by the contact of different metals with the living as well as with the dead body. Weber observed the development of galvanic electricity, not merely from the contact of copper with zinc, brought into connection by means of a metallic conductor, but also from the contact of the body with two portions of copper, when a circle was formed with them. He has likewise noticed the production of thermo-electricity in the animal body; it was manifested when the ends of an arch of copper were held in the hands, of which one was immersed in cold, the other in hot water. In this respect, therefore, the animal body exactly resembles the metals. M. Weber found that if a bar of iron was held near the muscles of the body when they were made to contract, the magnetic needle moved. But it remains a question, which he reserves for further experiments, to determine how far the motion of the needle depended on galvanic currents in the animal body, and not on disturbance of the magnetic state of the iron bar from other causes. Several physiologists, as Hunter, Abernethy, Prochaska, Prevost and Dumas, Dutrochet, and others, have attributed many processes in the animal body to electric action. In treating of the nervous system, I shall show, however, that although, as appears from many experiments, electric actions can be generated in the nerves, still the mode of action of the nerves is wholly different from that of electricity. Among modern physiologists, no one has carried the hypothesis of electricity being the cause of vital phenomena to a more extravagant length than the chemist Meissner.*

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[*] This subject is more particularly discussed in the Book on the Nervous System.

[†] Magendie, Journal de Physiol. v. 5.

[‡] Matteuci, L'Institut. No. 75.

[§] Experimenta in electricitatem sanguinis, urinæ, et bilis, Mem. d. A. d. Tor. v. 81.—Froriep, Not. 19, 177.

Pouillet has endeavoured to prove, that during the vegetation of plants, an abundance of electricity is developed. He first investigated the generation of electricity in the formation of carbonic acid. His experiments† must be repeated with the necessary modification on incubated eggs, and on animals, with reference to the formation of carbonic acid during respiration.

2. *Of the generation of caloric.*

The temperature of the human body in those internal parts which are most easily accessible, such as the mouth and rectum, is 97·7° or 98·6° Fahr. The temperature of the blood is found to be from 100⅗° to 101¾°; M. Magendie states it at 101·75°; Thompson at 101°; in some diseases it is as high as from 106° to 107°. In the *morbus cœruleus*, in which there is defective arterialisation of the blood from malformation of the heart, the temperature of the body is often several degrees lower than natural; for instance, as low as 79° or 77½°; in the Asiatic cholera, a thermometer placed in the mouth rises only to 77° or 79°. The temperature of the body in health is, according to Autenrieth, 1½° Fahr. lower during the day; and somewhat lower in the morning than in the evening. In warm climates, Dr. Davy found the temperature of the interior of the body to be from 2·7° to 3·7° Fahr. higher than in temperate climates; he observed this difference of temperature in individuals of different ages, and in natives as well as in persons coming from cooler climates. This last observation is, however, quite opposed to the results of Douville's experiments.‡ During the voyage of the Bonite,§ the French naturalists had an opportunity of observing the influence of climate on the human body. Their observations (more than 4000 in number) were commenced in April 1836, and continued, with few interruptions, every day at 3 o'clock P. M. until November 6th, 1837. The subjects were eight sailors, and two men who worked in the hold of the ship. The results obtained were, that the temperature of the human body rises and falls, though in a slight degree only, with the external temperature; that it falls slowly in passing from hot to cold climates, and rises more rapidly in returning towards the torrid zone: but that these changes in the temperature of the body are more considerable in some individuals than in others. The temperature of the ten men at Cape Horn, lat. 59° S. when the temperature of the air was 0° C. or 32° Fahr. differed only about 1° C. or 1$\frac{1}{5}$° Fahr. from the mean temperature of the same men when at the Ganges, near Calcutta, in an external temperature of 40° C. or 104° Fahr. According to the observations of MM. Becquerel and Breschet, the temperature of the body is the same in individuals living at high elevations on mountains and in those inhabiting the plains below.

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* System der Heilkunde aus den allgemeinsten Naturgesetzen. Wien, 1832.

† Annal. de Chim. et de Phys. 35, 420.

‡ Froriep, Notizen, N. 686.

§ Comptes Rendus, 1838, p. 456.

Temperature of mammalia and birds.—Tiedemann and Rudolphi have collected all the facts known relative to the temperature of different animals.

The following is derived from the more copious table of Tiedemann:—[*]

The Ox	has a temperature of from	99° to 104° Fahr.
Sheep		100·40° to 104°.
Horse		97° to 98·24°.
Elephant		99·5°.
Guinea-pig		96 37° to 100·40°.
Hare		100°.
Rabbit		99·46° to 104°.
Squirrel		105°
Seal		102°.
Dog		99·30° to 100·30°.
Cat		98·60° to 103·60°.
Bat.—Vespertilio noctula		102°.
———Vespertilio pipistrellus		105° to 106°.
Ape.—Simia aigula		103·86°.
Porpoise.—Delphinus phocæna		96·90° to 99·50°.
Narwhal.—Monedon monoceros		96°.
Whale.—Balæna mysticetus		102°.

From this table it appears, that the heat of the body varies in the different genera of mammalia; and it is also seen, that there is no remarkable difference between the cetacea and the other mammalia in respect to their temperature.

The temperature of the body in birds seems, from the following table, which is also taken from Tiedemann, to be, almost without exception, higher than in man and mammalia:—

The gull.—Larus	has a temperature of	100° Fahr.
White game.—Tetrao albus		102°.
Common cock		102·99° to 103·78°.
Common hen		102·99° to 109·94°.
Pigeon		106·70° to 109·58°.
Duck, different species		106° to 111°.
Bearded vulture.—Vultur barbatus		107·49°.
Falco, different species		104·50°. to 109·74°.
Raven.—Corvus corax		105·99° to 109·23°.
Fringilla, different species		107° to 111·25°.
Great titmouse.—Parus major		111·25°.
Hirundo lagopus		111 25°.

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[*] Tiedemann, Physiologie, i. 454. The English translation, 234.

Production of animal heat in old age and early life.—Edwards found the power of generating heat to be less active in old people. It was shown by the experiments of Autenrieth and Schuetz,* that the embryo of Mammalia owes its heat to the mother, and loses it when removed from the uterus. The same rapid diminution of temperature was observed by M. Edwards in the new-born young of most carnivorous and rodent animals when they were removed from the parent, the temperature of the atmosphere being between 50° and 53½° Fahr.; whereas, by lying close to the body of the mother, their temperature was only 2 or 3 degrees lower than hers. The same law applies to the young of birds. Young sparrows, a week after they were hatched, had a temperature of 95° to 97°, while in the nest; but when taken from it, their temperature fell in one hour to 66½°, the temperature of the atmosphere being at the time 62½°. Other experiments, which M. Edwards instituted, showed, that the want of feathers is not the cause of this rapid cooling.† It appears from his investigations, that several kinds of mammiferous animals are born in a much less perfectly developed condition than others: that the young of dogs, cats, and rabbits, for example, are far inferior in the power of generating heat, to the young of other animals which are not born blind. In fourteen days this defect is removed, and they have then reached the stage at which the young of those of other animals are born.‡ The need of external warmth to keep up the temperature of new-born children is well known; it is not less necessary, indeed, than to the young of carnivorous and rodent animals. The statistical researches of M. Edwards have shown that the want of external warmth is a much more frequent cause of death in new-born children than has been hitherto supposed.(*a*)§

Effects of cold on adult warm-blooded animals.—Hybernation.—The generation of caloric in adult warm-blooded animals is in a certain measure independent of external temperature: this independence, however, varies in degree according to the geographical distribution, and the internal vital conditions of the animal; hence the migration of many animals with the change of the seasons. It appears from Captain Parry's observations, that the mammiferous animals of polar regions will support the temperature at which mercury freezes, namely,—40° Fahr., or even a temperature as low as—51° Fahr.‖ There are some Mammalia, however, namely, the hybernating animals,—the marmot, rellmouse, hamster, hedgehog, great dormouse nine or ten times in the same period. During the state of the deepest torpor, however, respiration ceases entirely; and the animals may then, if Spallanzani's observation is correct, be placed with impunity in an irrespirable gas. Saissy found that, until this last state ensues, they continue to remove the oxygen from the air; the quantity of oxygen consumed decreasing as their temperature falls: but that the absorption of oxygen still continues, together with the exhalation of carbonic acid, as long as any of the former gas remains in the air; whereas animals which do not hybernate, such as rabbits, rats, and sparrows, die when they have consumed a small portion only of the oxygen of the air contained in the vessels. M. Prunelle states that the arterial blood of the bat is less bright in colour during hybernation. With respect to the circulation, Saissy found that, at the commencement and towards the termination of the state of hybernation, the motion of the blood is extremely slow; and that when the torpor is complete, the capillaries of the extreme parts are almost empty, and the large vessels only half distended. It was only in the larger trunks of the chest and abdomen that an undulatory motion of the blood was still observable. In the bat, during hybernation, the heart beats, according to Prunelle, only fifty or fifty-five times, according to Dr. M. Hall[*] only twenty-eight times, in the minute, while ordinarily it beats about two hundred times in the same interval. Sensibility, as tested by mechanical or galvanic stimulants, is diminished, but it is not entirely wanting, except during the state of the deepest torpor. The statement that the irritability of the muscles is diminished in hybernating animals appears to be incorrect. The observations of M. Mangili[†] and Dr. M. Hall show, that the irritability both of the heart and the voluntary muscles continues much longer after death than it ordinarily does in warm-blooded animals. In this circumstance, and in the continuance of the heart's action, though the respiration is nearly suspended, and the blood circulating in the arteries nearly venous, hybernating animals, as Dr. Hall remarks, resemble reptiles. Sensation and volition are suspended during hybernation, but the excitability of the parts of the nervous system engaged in the production of the reflex movements remains. A slight touch applied to one of the spines of the hedgehog causes it to draw a deep inspiration; the least disturbance induces motion in the animal.[‡] The secretions do not wholly cease; for Prunelle found that bats lost $\frac{1}{32}$ of their weight between the 19th of February and the 12th of March.

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* Experimenta circa calorem fœtus et sanguinem. Tub. 1799.

† Froriep, Notizen, 151.—Edwards, On the Influence of Physical Agents on Life, translated by Drs. Hodgkin and Fisher, Philad. Edit.

‡ Compare Legallois, Meckel's Archiv. iii. 454.

§ Edwards, loc. citat.

‖ See Tiedemann, loc. cit. pp. 461, 466. Translation, p. 236.

(*a*) The fact itself, notwithstanding its vital importance, is too often overlooked in the cases of the scantily clothed and half denuded children of wealthy parents. Fashion has more weight than physiology; even when physicians press this latter into their aid. In the present case, however, the latter are, in general, singularly oblivious, we must not say ignorant, of an important and useful principle.

Saissy states, moreover, that the blood of hybernating animals (the marmot and hedgehog) is remarkable for the small quantity of fibrin and albumen which it contains; that the bile is sweetish, but that the fat is unchanged. According to Prunelle and Tiedemann,[§] an apparently glandular, but really fatty, mass forms on the neck and anterior mediastinum before hybernation: this fatty mass, Jacobson[||] remarks, was incorrectly compared with the thymus gland. Otto[¶]

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[*] Philos. Transact. 1832, p. 17.

[†] Ann. du Muséum. t. x.

[‡] Cyclop of Anat. art. Hybernation.

[§] Meckel, Archiv. t. i. p. 481.

[||] Ibid. iii. 151, 152.

[¶] N. act. ac. cæs, nat. cur. t. xiii. p. 1.

has discovered a vessel, which might be compared to the internal carotid, passing through the stapes of the tympanum in several genera: all of which, he says, are subject to a state of more or less complete hybernation. Hyrtl has observed the same structure in the guinea-pig also; while he finds it wanting in the rellmouse. A similar artery, but of very small size, sometimes exists in man. The assertion of Mangili, that the cerebral vessels are remarkably small in hybernating animals, is denied most expressly by Otto, who also did not observe the large size of the nerves of the superficial parts, which was spoken of by Saissy. It is generally known that, during hybernation, a part of the fat formed in the autumn is consumed to nourish the body; but the experiments of Pallas, who produced hybernation during the height of summer by means of artificial cold, prove the incorrectness of the theory which supposes that it is the accumulation of fat and the enlargement of the glands in the chest and neck during the autumn, which induce hybernation, by exerting pressure upon the respiratory nerves. The spinal cord is very short in the hedgehog; but this is not a general character of hybernating animals.[*]

Cause of hybernation.—Before all the facts, presently to be noticed, with respect to the cause of animal heat were considered, no inquiry concerning the spontaneous diminution of this power of generating heat during hybernation, and the causes of this latter phenomenon, could be attended with any satisfactory result. The phenomenon of hybernation as presented by a few animals must not be considered in an isolated manner, but the investigation should be grounded upon the fact, that all animals, when the external temperature falls below a certain point, become torpid, without thereby entirely losing the capability of living. The point to which the external temperature may be lowered without the state of torpor being induced, varies very much according to the organisation of the different animals, and their geographical distribution.

1. Man evidences in this respect a very great tenacity of the organic powers; since, under favourable circumstances, he maintains his proper temperature in all climates in which animals exist,—in the extreme north, as well as under the equator. But even man, when deprived of necessary covering and acted on by cold, or, in other words, deprived of a vital stimulus, falls into a state of torpor, and the more easily when his vital force is depressed by the influence of intoxicating substances.

2. Many animals fall readily into this state of torpor, when the necessary degree of external warmth in harmony with their geo-

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[*] The principal treatises on hybernation are:—Saissy, Recherches experimentales anatomiques sur la physique des animaux mammifères hybernans; Paris et Lyon, 1808; übersetzt von Nasse.—Reil, Archiv. für Physiol. t. xii. p. 293. Saissy, Mém. de Turin, 1810-1812.—Meckel, Archiv. für Physiol. t. iii.—Mangili über den Winterschlaf, in Reil's Archiv. Bd. 8.—Prunelle, Recherches sur les phénomènes et sur les causes du sommeil hivernal: Ann. du Mus. t. xviii.—Gilbert's Annalen, Bd. 40, 41.

graphical distribution is wanting. It is from the necessity of a certain external temperature that birds migrate.

3. The young of Mammalia become torpid at a temperature which is sufficiently elevated for maintaining the vital force of the adult animals in an active state. This is proved by the observations of Legallois, on rabbits six or eight weeks old, which however may be restored from the torpid state by raising the temperature of the medium.

Now, in all these cases the cold cannot exert a directly depressing influence on the respiratory process, and thus on the heat of the body: indeed, all the symptoms which usher in the torpor, namely, the insensibility, sleepiness, and debility, are indicative of depression of vital force from want of vital stimulus. The effect on the respiration must, therefore, be regarded as a consequence, not as the cause of the torpor, just as in the case of syncope from nervous affections. The diminution of the temperature of the body is likewise a consequence of the depression of vital energy, which may perhaps prevent the generation of caloric in the lungs, by primarily causing retardation of the respiratory movements, and rendering the respiratory process less active. The facility with which this state of torpor is induced in some animals arises, therefore, from the greater delicacy of their structure, and from the vivifying and stimulating influence of warmth being more necessary for the continuance of their organic processes. This must also be regarded as the cause of the winter sleep of hybernating animals, in which the only great peculiarity is, that in them the torpor may continue a long time without danger to life. Of the causes of hybernation advanced by Saissy and others, some are merely consequences of the depression of vital energy; others, such as the supposed large size of the external nerves and small size of the cerebral vessels, do not exist.

The hybernation of animals then is perfectly analogous to what is called the nocturnal sleep of plants,—the change of position of their leaves,—which is also occasioned by the want of the stimulus of light; and hence it is sometimes observed during the day, when plants are placed in the shade.* The ordinary sleep of animals, on the contrary, is by no means dependent on want of stimulus; but arises from the material change and exhaustion induced in the body by the state of action, and may, therefore, occur naturally at any time of the day, although from accidental causes it mostly comes on at night.

The *summer sleep* of reptiles and of the tanrec seems, on the other hand, to arise from a disturbance of the system induced by too much heat. The want of water also appears to be a main cause of this state, which may therefore be regarded as the effect of the deficiency of one vital stimulus, and of the excess of another.†

Effects of external heat on the temperature of warm-blooded animals.—If the temperature of the atmosphere in which a mammiferous animal is placed exceeds the natural heat of its body, a slight elevation takes place in the temperature of the animal's body, but not in proportion to the elevation of the external temperature. Experiments have been instituted by Duntze,* Fordyce, Banks, Blagden,† and Delaroche and Berger, to ascertain the effect of increased external heat on the temperature of the body. Sir C. Blagden and others supported a temperature varying between 198° and 211° Fahr. in a dry air for several minutes; in a subsequent experiment Blagden himself remained eight minutes in a temperature of 260°; Delaroche and Berger observed an elevation of temperature of a few degrees only in rabbits exposed to a heat varying from 122° to 194° Fahr. In birds, also, the heat of the body did not rise commensurately with that of the surrounding atmosphere; it did not undergo an elevation of more than 11° or 12°.‡ This power of maintaining nearly their original temperature when exposed to great external heat, is due to the cooling effect of the increased perspiration of animals under these circumstances. The correctness of this explanation is proved by the circumstance observed by Delaroche, that if the heated atmosphere is at the same time saturated with moisture which prevents exhalation taking place, the temperature of the animals rises 4°, 7°, even 9° higher than that of the surrounding medium. It must not, however, be forgotten that the increased evaporation from the surface of the body in a dry heat does not arise solely from physical causes; but that the external heat here excites an organic function. In fact, when there is great internal heat, evaporation is often prevented by internal causes; and in many fevers the skin is intolerably hot, merely from its being dry, and from perspiration being obstructed.

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* Journ. de Phys. 52, 124.

† See also Pastré, Nov. Act. Acad. Nat. Cur. 14, 661.

MM. Becquerel and Brechet§ have employed their thermo-electric apparatus to ascertain the effect produced on the temperature of the human body by immersion in hot water. They examined first the effect of immersion of parts of the body. The biceps muscles of the right arm of two young men having been ascertained to be equal in temperature, the arm of one was immersed for a quarter of an hour in water at 42° C. (or 107·6° Fahr.): an elevation in the temperature of the arm was produced amounting to ⅕° C. (rather more than ⅓° Fahr.) Immersion of the entire body during twenty minutes in a bath of the temperature of 49° C. (120⅕° Fahr.) caused the heat of the arm to rise from ⅕° to ⅗° C., the pulse beating at the same time 112 times in a minute. In another experiment the body was immersed in water of the temperature of 42·5° C. (108½° Fahr.) during twenty minutes without undergoing any rise of temperature, though the skin was reddened and the head congested. The temperature of the muscles of a dog rose successively ½° and 1½° C. in five minutes when it was immersed in water at 49° C. (120⅕° Fahr.)

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* Exp. calorem animalium spectantia. Lugd. Bat. 1754.

† Philos. Transact. 1775, v. 65.

‡ Delaroche and Berger, Exp. sur les effets qu'une forte chaleur produit dans l'économie animale. Paris, 1806.—Journal d. Phys. 71.—Reil, Archiv. 12, 370.

§ Comptes Rendus, 1838, i. 429.

The elevation of temperature took place principally when the animal became enraged.

Temperature of cold-blooded vertebrata, and effects of cold and heat on them.—It has been often said, though incorrectly, that cold-blooded animals have themselves no power of generating heat, but derive their temperature solely from the surrounding medium. With respect to Reptiles and Amphibia, the researches of Dr. Davy, Czermack, Wilford and Tiedemann, have proved that the temperature of these animals, although it generally falls with that of the surrounding medium to a certain point, is nevertheless mostly two or more degrees higher; and that although their temperature rises also with that of the medium, yet at a certain point it ceases to be higher, and at great degrees of heat is even lower than the external temperature.*

Tiedemann† found the temperature of frogs higher than that of the water around them; and at night, when the water generally was frozen, a frog had a temperature of 33° Fahr., and the water around it was unfrozen. Frogs seem, from the observations of Delaroche, to have also the power of preserving a low temperature in a great external heat by means of exhalation.

The experiments of Berthold, which appear to have been performed with great care, show, that the difference between the temperature of Amphibia and that of the surrounding medium is really very slight. He found that these animals had generally a lower temperature than the air, owing to the cooling effect of evaporation. In water, frogs were of the same temperature as the water. During the act of copulation, their temperature was ¼° to 1° R. or ½° to ¼° Fahr. higher than that of the water. Reptiles, when the external temperature is moderate or rather elevated, have a heat ½° to 1⅘° Fahr. higher than the air or water at the time.‡

Fishes appear, from the experiments of Martine, J. Hunter, Broussonet, Dr. Davy, and Despretz, to have a temperature one or two degrees higher than that of the surrounding water. Berthold detected no difference between the heat of fishes and that of the water around them. Dr. Davy ascertained that the temperature of a shark was 77° Fahr. when the temperature of the sea was 74⅔° Fahr. The observations of Dr. Davy§ on the elevated temperature of the thunny are extremely interesting. He found the temperature of the *Thynnus pelamys* to be 99° Fahr. when the thermometer placed in the surrounding water stood at 80½° Fahr. The common thunny was also reported by fishermen to have a high temperature. Whether this circumstance is in any way dependent on the presence of the vascular plexus, discovered by Eschricht and myself in connection with the vena porta and arteries of the abdominal viscera in these fishes, must be determined by further observations on them and on the other fishes in which we have found the same vascular structures, namely, the *Squalus cornubicus* and the *Squalus vulpis.*[*]

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* See the numerous experiments of Czermack on the temperature of reptiles in Baumgaertner's and Ettinhausen's Zeitschrift für Physik und Mathematik, 3 Bd. 384. Froriep, Notiz. 579.—Philos. Trans. 1814.—Jameson's Journal, v. xix.

† Tiedemann, Physiol. i. Translation by Drs. Gully and Lane, p. 240.

‡ Neue Versuche über die Temperatur der Kaltblütigen Thiere. Götting. 1835. Müller's Archiv. 1836, Jahresbericht, p. cxix.

§ L'Institut. 108. [Philos. Trans. 1835.]

Some cold-blooded animals also present the phenomenon of hybernation. Sir J. Franklin relates, that in the arctic regions many fishes, when laid upon the ice, instantly became torpid, but recovered again after several hours or days. It has, however, been frequently asserted, that fishes continue to live in ice, and that the water around them is not frozen.[†] Pallas[‡] relates, that Crucians (*Cyprinus carassius*) are restored to life on the melting of the lakes in Siberia, which were frozen to the bottom; and mentions a similar fact observed by Bell, namely, the revival of gold-fishes from frozen water. Reptiles become torpid not only during winter, at the commencement of which they bury themselves, but during summer also, in hot climates. In the dry season reptiles bury themselves and fall into a state similar to hybernation, from which they recover in the rainy season. Humboldt has observed some very interesting facts of this kind. In warm-blooded animals there is only one known instance of this summer sleep; that is in the Tanrec,—the hedgehog of Madagascar.

Temperature of invertebrate animals.—Complete observations on the temperature of invertebrate animals are still wanted; but the facts already known prove that their temperature, like that of the other cold-blooded animals, varies with the temperature of the medium. That it may, nevertheless, even in insects, be a degree or two higher or lower than the external temperature, is evident from the experiments of Martine, Hausmann, Rengger, and Dr. J. Davy; while in beehives and anthills, a very much higher temperature has been observed. In his numerous observations, Mr. Newport[§] was always able to detect a certain degree of independent heat even in single insects, provided they were in a state of activity; and sometimes the temperature of the insect was as much as 20° above that of the surrounding air. In the river crawfish, Rudolphi saw the thermometer, which in the water was at 52¼°, rise to 54½°, and even to 59° F. Similar evidences of independent heat, though less considerable, have been observed in the mollusca.[‖] In snails the temperature is two degrees higher than that of the atmospheric medium.

The insects and mollusca, of temperate and cold climates at least, are known, with certainty, to be subject to hybernation. Some of the lower animals seem to require a pretty high external temperature. The instance of the small snail,—the *Cyclostomum thermale*, Ranzani,—which lives in the warm springs of Albano, the temperature of which is 83¾° F. appears extraordinary. Rudolphi saw these animals move briskly even in water of 99½° F. But the Entozoa of man and Mammalia live in an equal, those of birds in a still higher temperature. Rudolphi remarks, that the Entozoa of warm-blooded animals become torpid and appear dead in the cold, but revive when placed in warm water; while the Entozoa of cold-blooded animals bear a low as well as a high temperature.

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[*] See Eschricht and Müller in the Abhandl. der Acad. der Wissench. Zu Berlin vom Jahn. 1836, und Nachtrag.

[†] Jahresbericht der Schwed. Acad. übersetzt von J. Müller, 1824.

[‡] In Rudolphi's Grundriss der Physiologie, i. 176.

[§] Philos. Transact. 1837, p. 271.

[‖] An account of the different observations relative to this subject will be found in Rudolphi's Physiologie, 179; in Treviranus, Biologie, 5—20; and in Tiedemann, Physiol. 476. Translation, p. 244.

The hybernation of snails has been described by Gaspard: he says that, during this state the heart ceases to beat; respiration is no longer carried on; and the tentacula, if cut off, are not reproduced. These animals also fall into a summer sleep when the heat is great; but, in the summer sleep, respiration, the heart's action, and the reproductive power are not interrupted.[*]

SOURCES OF ANIMAL HEAT.

I now proceed to investigate the means by which heat is generated in the animal body. The first point of interest in this inquiry is the difference of temperature of different parts of the body. The temperature is lower, the further removed the part is from the centre of the body. Thus, in the human subject, a thermometer placed in the axilla stood at 98° F., at the loins it indicated a temperature of 96½°, on the thigh 94°, on the leg 93° or 91°, on the sole of the foot 90.°[†] Dr. J. Davy found the temperature of the rectum, in several experiments, somewhat higher than that of the brain: this appears extraordinary, and probably arose from some error of observation. MM. Breschet and Becquerel in investigating this subject employed the thermo-electric multiplicator. Into the part of which the temperature was to be examined, they thrust a needle composed of two different needles united at the point, and connected the other ends of the needles with the wires of the multiplicator. They found the temperature of muscle (at the depth of four centimeters) from 2° to 1·25 centim. higher than that of the subcutaneous cellular tissue, (at the depth of one centimeter), a difference which may be ascribed to the loss of heat at the surface of the body. The mean temperature of the muscles in man was 36·77° C. or about 97° Fahr. In the dog the temperature of the thorax, abdomen, and brain, was the same as that of the muscles. Dr. Davy's experiments on the temperature of the different kinds of blood are very interesting. Eleven experiments were instituted on sheep and oxen; and from the mean of these experiments it would appear, that the temperature of arterial blood is about 1° or 4½° F. higher than that of venous blood.* Mayer† found the temperature of the blood of the jugular vein to be from 1° to 2° R., or from 2¼° to 4½° F. lower than that of the blood of the carotid; but he could not discover the difference of temperature of the blood of the two sides of the heart, which is spoken of by Davy. Saissy has made similar observations on hybernating animals. MM. Becquerel and Breschet‡ have further investigated this subject, employing the thermo-electric multiplicator. The mean difference between the temperature of the venous and arterial blood of the aorta and vena cava descendens in the dog was found by them to be 1·01° C. or 1·82° F.; the mean difference between the arterial and venous blood of the femoral artery and vein was 0·90° C. or 1·62° F. The temperature of the blood of the left auricle in a Turkey was 0·90° C. or 1·62° F. higher than the blood of the right auricle. The temperature of the blood both of the arterial and of the venous system diminishes from the heart towards the extremities.

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[*] Meckel, Archiv. 8.

[†] Dr. J. Davy, Phil. Transact. 1814.—Meckel, Archiv. ii. p. 312. See also J. Hunter's experiments in his Treatise on Animals producing heat. Works. Palmer's edition, vol. iv. p. 145. Also his complete works. Philadelphia edit.

1. *Theory of the production of heat in respiration.*—According to the theory of respiration, invented by Lavoisier and Laplace, and adopted by most modern chemists, the oxygen of the atmosphere combines in the lungs with the carbon of the blood, and is expired in the form of carbonic acid; and if more oxygen disappears from the atmosphere than is accounted for by the carbonic acid expired, it is supposed, according to a second hypothesis, that this portion of the oxygen which does not go to form carbonic acid, unites with hydrogen in the blood, and forms water, which is exhaled. Admitting these hypotheses, it might be imagined that the source of animal heat was the caloric developed during the combination of the oxygen with the carbon and hydrogen in the lungs. To render this more probable, and to explain more easily the distribution through the body of the caloric, when developed, Dr. Crawford§ stated, that arterial blood has a greater capacity for caloric than venous blood, in the proportion of about 11·5 to 10. Thus he supposed, that the caloric developed in the lungs at first served to maintain the temperature of the arterial blood; and that afterwards, during the conversion of this arterial blood into venous blood in all parts of the body, the heat, before latent in the former, was set free. Dr. J. Davy has, however, shown that the capacity of the two kinds of blood for caloric differs, either not at all, or only very slightly, as in the proportion of 10 to 10·11.

But, supposing that Lavoisier's theory of respiration is correct, the amount of caloric that can be generated by the respiratory process may be ascertained by direct calculation. This calculation has been made by Dulong and Despretz. Dulong introduced different mammiferous animals, carnivorous as well as herbivorous, into a receiver, in which the changes produced in the air by respiration, and the volume of the different products, could be determined; at the same time that the amount of caloric lost by the animal could be ascertained. Dulong found, that all animals extracted from the air more oxygen than was accounted for by the carbonic acid which they exhaled. In herbivorous animals, the oxygen thus lost amounted on an average to $\frac{1}{10}$ only of the whole quantity of the same gas extracted from the air; in carnivorous animals, the maximum quantity of this oxygen, which was not converted into carbonic acid, was $\frac{1}{2}$, the minimum $\frac{1}{3}$, of the whole amount of oxygen consumed. If, now, it be admitted, that, by the conversion of the oxygen into carbonic acid during respiration, the same quantity of caloric is developed as, according to Laplace and Lavoisier, is produced by the combustion of carbon in oxygen gas, it will be found by calculation that only $\frac{7}{10}$ of the heat that is lost during a given time by herbivorous animals, and $\frac{1}{2}$ of that which carnivorous animals lose in the same space of time, can be thus accounted for. Again, admitting that the oxygen, which is converted into carbonic acid, is consumed in forming water by uniting with hydrogen, and that as much caloric is thus generated as would be developed during the combustion of equal quantities of oxygen and hydrogen, still the whole quantity of caloric produced by the combination of carbon and hydrogen with the oxygen, would amount only to from $\frac{3}{4}$ to $\frac{4}{5}$ of that which is developed during the same space of time by carnivorous as well as herbivorous animals.*

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* Davy, Tentamen experimentale de sanguine. Edinb. 1814.—Meckel, Archiv. i. 109.—Phil. Transact. 1814.

† Meckel's Archiv. iii. 337. ‡ L'Institut. 190.

§ Dr. Crawford, on animal heat.—Versuche und Beobachtungen über die Wärme der Thiere. Leipsic, 1799.

Despretz placed animals in a vessel surrounded with water; an uninterrupted current of air to and from the vessel was maintained, and the volume and composition of the air employed were ascertained both before and after the experiment, which was continued 1½ or 2 hours, as well as the increase in the temperature of the surrounding water during this period: by this means it was found that the heat, which should have been generated in the respiratory process according to Lavoisier's theory, would account for from 0·76 to 0·91 only of that which the animals really gave out during the same time.†

From these experiments it results, that, even if the chemical theory of respiration is adopted, there must be still some other source of animal heat. But it is exceedingly improbable that the water exhaled from the lungs is formed during the respiratory process by the union of its elements; it is much more likely that a part of the oxygen is retained by the blood. The heat derived from the union of the oxygen and carbon is, therefore, all which can be taken into account, and this would, according to Dulong, amount in herbivora to $\frac{7}{10}$ only, and in carnivora to $\frac{1}{2}$ only of the heat really developed in the body. Besides, it is at present merely an hypothesis that the oxygen of the atmosphere unites with the carbon in the lungs to form carbonic acid. According to another view, which would explain the phenomena equally well, and which the still later experiments of Bischoff, Magnus, and Dr. Davy seem to establish as correct, the oxygen combines with the carbon in the course of the circulation, and thus imparts to the blood a higher temperature. Wherever the carbonic acid is formed,—whether in the lungs or in the blood,—the oxygen inspired would in either case be the proximate cause of its formation, and the respiration therefore might be regarded as a cause, mediate or immediate, of animal heat; and, adopting the results obtained by Dulong, it might be admitted that in herbivora $\frac{7}{10}$, in carnivora $\frac{1}{2}$, of the animal heat is generated by the respiratory process. This being conceded, it would be easy to explain not only the want of perceptible independent heat in the embryo, in which no oxygen is inspired, but also the circumstance that the subjects of the *morbus cœruleus* (in whom respiration is impeded from defect of the circulatory organs), have sometimes a temperature some degrees lower than natural, as well as the small degree of independent heat possessed by cold-blooded animals (in which only a part of the blood is aerated, as in reptiles, or in which respiration is performed only by means of the air dissolved in water, and is consequently less perfect). To put the chemical theory of animal heat to a decided test, experiments must be instituted on the plan of those of Dulong and Despretz, but on cold-blooded in place of warm-blooded animals, to ascertain whether, calculating from the changes produced in the air by their respiration, the quantity of caloric generated by the chemical process would not be too large to account for the very small quantity of heat evolved. This is an interesting problem for chemical inquiry. The main fact, however, of the vast influence which respiration exerts over the evolution of animal heat, is undoubted, although we may fail to find either a chemical or a physiological explanation. The observations of Mr. Newport (Philos. Transact. 1837) are very interesting. He shows that the larva, in which the respiratory organs are smaller in comparison with the size of the body, has a lower temperature than the perfect insect. Flying insects have the highest temperature, and they have always the largest respiratory organs, and breathe the greatest quantity of air; while, among terrestrial insects, those produce the most heat which have the largest respiratory organs and breathe the most air. During sleep, hybernation, and the state of inaction generally, respiration is slower or suspended, and the temperature is proportionally diminished; while on the other hand, when the insect is most active and respiring most voluminously, its amount of temperature is at its maximum, and corresponds with the quantity of respiration. Neither the rapidity of the circulation nor the size of the nervous system, according to Mr. Newport, presents such a constant relation to the evolution of heat.(*a*)

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* Berzelius, im Schwedischen Jahresbericht. Bonn, 1824, p. 67.—See also Neues Journal für Chemie und Physik. N. R. Bd. 8. S. 505.

† Gmelin, Chemie, tom. iv. p. 1523.—Ann. d. Chim. et de Phys. 26, 338.

(*a*) The chemical theory, of animal heat being developed in the combination of oxygen with carbon and hydrogen, ought not to rest on any particular theory of respiration, nor require for its support more than the general fact, that oxygen finds entrance into the blood, and with this fluid reaches all parts of the organism. It is during this time, or, to be more specific, from the moment of oxygen penetrating

2. *Generation of heat in the organic processes.*—There must be other sources of animal heat, besides respiration. Some physiologists, and among them Professor von Walther and Dr. Paris, have thought to find a principal source of animal heat in the different secreting processes, by which fluids having a less capacity for caloric than the blood are separated from the latter fluid, since caloric before latent must thereby be rendered sensible. According to Dr. Crawford, the capacity of milk for caloric is less than that of the blood. Dr. Paris* estimates the capacity of urine for caloric at 0·777, that of arterial blood at 1·003. These results are, however, directly

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the pulmonary mucous membrane, and entering into the radicles of the pulmonary veins, to that in which it is conveyed to all the tissues by the delicately reticulated arterial or aortic capillaries, that it is continually undergoing combination with other elements, and in a more especial and constant manner with carbon and hydrogen. Not then in the circulation, but in the conversion of blood into various secretions, by this union of oxygen with carbon and hydrogen, is caloric evolved. Respiration, as the chief means of introducing oxygen into the body, is the chief supporter, but not the creator, of animal heat. It furnishes the pabulum, oxygen, or the material for combination, but the combination itself (of oxygen with carbon and hydrogen) is a separate process, just as chylosis is separate from chymoses, or secretion from circulation. The origin and real character of the process of the development of animal heat is well expressed by Liebig, in the following passage of his *Animal Chemistry:* "The mutual action between the elements of the food and the oxygen conveyed by the circulation of the blood to every part of the body is *the source of animal heat.*" The elements of the food here mentioned are carbon and hydrogen.

"According to the experiments of Despretz, 1 oz. of carbon evolves, during its combustion, as much heat as would raise the temperature of 105 oz. of water at 32° to 167°, that is, by 135 degrees; in all, therefore, 105 times 135°=14207 degrees of heat. Conseqnently, the 13·9 oz. of carbon which are daily converted into carbonic acid in the body of an adult, evolve 13·9×14207°=197477·3 degrees of heat. This amount of heat is sufficient to raise the temperature of 1 oz. of water by that number of degrees, or from 32° to 197509·3°; or to cause 136·8 lbs. of water at 32° to boil; or to heat 370 lbs. of water to 98·3 (the temperature of the human body); or to convert into vapour 24 lbs. of water at 98·3°.

"If we now assume that the quantity of water vaporized through the skin and lungs in 24 hours amounts to 48 oz. (3 lbs.), then there will remain after deducting the necessary amount of heat, 146380·4 degrees of heat, which are dissipated by radiation, by heating the expired air, and in the excrementitious matters.

"In this calculation, no account has been taken of the heat evolved by the hydrogen of the food, during its conversion into water by oxidation within the body. But if we consider that the specific heat of the bones, of fat, and of the organs generally, is far less than that of water, and that consequently they require, in order to be heated to 98·3°, much less heat than an equal weight of water, no doubt can be entertained, that when all the concomitant circumstances are included in the calculation, the heat evolved in the process of combustion, to which the food is subjected in the body, is amply sufficient to explain the constant temperature of the body, as well as the evaporation from the skin and lungs.

"All experiments hitherto made on the quantity of oxygen which an animal consumes in a given time, and also the conclusions deduced from them as to the origin of animal heat, are destitute of practical value in regard to this question, since we have seen that the quantity of oxygen consumed varies according to the temperature and density of the air, according to the degree of motion, labour, or exercise, to the amount and quality of the food, to the comparative warmth of the clothing, and also according to the time within which the food is taken."—*Liebig, Op. cit.*

* **Lond. Med. and Physic. Journal, 21, 1809.—Meckel, Archiv. ii. 308.**

opposed to those obtained by Dr. Nasse, who found no difference, as regards their capacity for caloric, between the different secretions and water; while Dr. Davy also detected scarcely any difference in this respect between the blood and water. M. Pouillet[*] has directed attention to another source of heat in the vital processes. All solid bodies, inorganic as well as organic, undergo an elevation of temperature when moistened with different fluids. This elevation of temperature is much greater in organic substances; in several cases M. Pouillet found that it amounted to from 11° to 18° of Fahrenheit. The solution of the food by the fluids of the stomach might be taken as an example, and perhaps the slight increase of heat which attends digestion might be thus explained. But a more considerable and more general source of animal heat is undoubtedly to be found in the organic processes, in which by the operation of the organising forces on the organic matter heat is generated, not in one, but in every organ of the body: hence it is, that in cases of long fasting, in which the separation of the old, but not the organisation of new matter continues, the temperature of the body, according to Martine, falls considerably, even to the extent of several degrees, although at the same time the source of caloric in the formation of carbonic acid remains. A case of stricture, or closure of the œsophagus, related by Dr. Currie, seems however to contradict this. In inflammation, the flow of blood to the part is increased, and the temperature is at the same time elevated; but Dr. J. Thomson[†] thinks that it never rises higher than the temperature of the blood in the great vessels. In scrofulous tumours in a state of active inflammation, MM. Becquerel and Breschet found the temperature raised as much as 5¼° F. Muscular contraction, also, they state, is attended with an elevation of temperature in the part to the extent of 1⅘° or 3⅗° Fahr. It was also observed by the same writers that a feverish state of the body caused its temperature to rise to 5½° F.; while, as is well known, the depression of vital energy in nervous affections, and in rigors, causes the temperature of the body to fall, although respiration is unaffected. Dr. Currie[‡] found the temperature in the palm of the hand during syncope to be as low as 63° F.

3. *Influence of the nerves in the generation of heat.*—Now, since all organic processes are chiefly dependent on the influence exerted by the nerves on the organic matter of the body, it cannot appear wonderful if the reciprocal action between the organs and the nerves is a main source of animal heat. The experiments of Brodie, Chaussat, and others, have proved this. Elliot and Home have observed that, after division of the nerves of a limb, its temperature falls, and this result is confirmed by the observation of all experimenters as to the effect of division of the nervus vagus. The diminution of temperature is detectible by a thermometer; the mere sensation of cold after injury to the nerves of a limb must not be

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[*] Ann. Chem. Phys. 20, 141.—Meckel, Archiv. viii. 233.

[†] Lectures on Inflammation. Edinb. 1813, p. 46.

[‡] Currie, Wirkungen, des Calten, und Warmen Wassers. Leipsic, Bd. i. 267. Currie on Cold Affusion.

confounded with it. Mr. Earle* found the temperature of the hand of a paralysed arm to be 70° Fahr. while that of the sound side had a temperature of 92° Fahr. On electrifying the limb, the temperature rose to 77°. In another case the temperature of the paralysed finger, was 56° Fahr. while that of the unaffected hand was 62°. MM. Becquerel and Breschet, however, detected no difference between the temperature of the sound limb and that of the paralysed limb in hemiphegia.

Sir B. Brodie† stated as the result of his experiments that, if artificial respiration was kept up in animals killed by decapitation, division of the medulla oblongata, destruction of the brain or poisoning with Woorara poison, the action of the heart continued, and the blood underwent the usual changes in the lungs, as shown by the analysis of the air respired, but that the heat of the body was not maintained: on the contrary, that it became cold more rapidly than the body of an animal in which artificial respiration was not kept up, being cooled by the air forced into the lungs.

However they may have been opposed by others, (Legallois, Hale, Wilson Philip,) Brodie's experiments are, still, for the main point, convincing. He has shown, that living rabbits expire 28·22 cubic inches of carbonic acid in half an hour; that, when artificial respiration is kept up in rabbits after death by poisoning, or destruction of the medulla oblongata, a quantity of carbonic acid, varying from 20·24, or 25·55 to 28·27 cubic inches, is still exhaled; thus, that under these circumstances, the products of respiration are nearly the same as ordinarily during life, and that, nevertheless, the temperature falls six degrees of Fahrenheit in the course of an hour after the division of the medulla oblongata.‡ The sinking of the temperature of the body, which Legallois stated to be constant in animals fastened down upon their back, was not observed by Chaussat§ in dogs; on the contrary, Chaussat confirms Brodie's observations. After injury of the brain, the temperature fell from 104° to 75° Fahr. before death, which occurred in from eleven to twenty-two hours. Division of the nervus vagus, which, without essentially affecting the chemical process of respiration, produces death, according to Legallois, by inducing congestion of the lungs with serum or blood, caused the temperature of the body to fall, during a period varying between twelve and thirty-six hours, as low as 97° or 98½° Fahr. and at last even to 68°. In all these experiments, unfortunately, the temperature of the atmospheric air is not mentioned. Injuries of the spinal marrow produced more striking effects on the animal heat, the higher the seat of the injury; so that the effects on the generation of caloric, like other consequences of lesions of the spinal cord, were greater in proportion to the number of nerves arising below the point of injury.

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[*] Earle, in Med. Chirurg. Transact. vii. 173. Meckel, Archiv. iii. 419.—See also Yelloly, in Med. Chir. Transact. iii.

[†] Phil. Trans. 1811, 4; 1812, 378.

[‡] See Nasse's Remarks on Brodie's experiments in Reil's Archiv. xii. p. 404.

[§] Meckel, Archiv. vii. 282.

Chaussat endeavours, lastly, to prove, that the sympathetic nerve also has a great share in the production of animal heat: but he attributes undue importance to inconclusive experiments, which prove little or nothing, and he does not perceive how many objections might be made to them.

Several of the facts which we have mentioned prove, however, that the influence of the nerves in the organic processes of the body, contributes greatly to the production of animal heat in other parts than the lungs. Berzelius is also of this opinion, which moreover seems to derive confirmation from the rapid and momentary increase of temperature, sometimes general, at other times quite local, which is observed in states of nervous excitement; from the general increase of warmth of the body, sometimes amounting to perspiration, which is excited by passions of the mind; from the sudden rush of heat to the face, which is not a mere sensation; and from the equally rapid diminution of temperature by the depressing passions. All these phenomena, however, might be explained by the increased or diminished flow of blood to the part, and in some cases also by a change induced in the heart's action. From the facts at present known, we deduce the inference, that elevation of temperature takes place in all organic processes, but that it is in part determined by the influence exerted on these processes by the nerves.(*a*)

(*a*) Liebig (*op. cit.*) objects to the opinion of the nervous system's generating caloric, except in an indirect manner, through its influence on respiration and the organic processes, all of which are modified in their rates and completeness of introducing and disposing of oxygen by nervous influence. This, however, is nearly all that is supposed by the enlightened physiologists who advocate nervous agency in the production of animal heat. Nobody, we believe, supposes that heat is struck out by the action of the nerves on other tissues with which they are connected or blended, as it would be by friction of two bodies, or by the combination of two electricities. By the excitement which they transmit to the respiratory function, the nerves accelerate it, and thus increase the introduction of oxygen into the blood; by that to the arteries and capillaries they quicken the circulation, and the ultimate changes, or secretions, by which oxygen combines with carbon and hydrogen, and thus furnishes animal heat. The nerves perform the same part in calorification as they do in the secretions in general. They do not furnish the pabulum, nor strike out the product—heat or secretion—by any electric or galvanic process: they simply accelerate, when they are themselves excited, and when they are depressed, they retard, the new combinations in the secreting capillaries, by which animal heat and animal secretions are evolved. But not only are the lungs modified in their rate of absorbing oxygen, but the heart also in that with which it circulates this oxygen, which reaches its left side after being mixed with the blood of the pulmonary veins.

That the apparatus for respiration and circulation and innervation are, after all, but instruments for spreading the materials and quickening their combinations, but not essentially necessary for forming these combinations and evolving their result, in animal heat and secretions, is manifest from the fact, that these phenomena take place in vegetable life, as in plants, which have neither lungs, nor circulation, nor nerves. Applied to some plants, as the arum, the thermometer has risen to 121° Fahr., the temperature of the surrounding air at the time being 66°. But, in denying lungs to plants, we cannot deny that a process goes on in them analogous to respiration in animals, viz. the absorption of oxygen, and its combination with carbon, and carbonic acid resulting, a process which takes place at the surface of the plants and mainly in their leaves. In some animals, as in frogs for

If now the warm-blooded and cold-blooded animals are compared, the cause of the difference of temperature in the two may be sought, either in the relative intensity of the respiratory process, or of the organic processes generally. Without referring one phenomenon to another as its cause, it may be remembered, that in cold-blooded animals the size of the central parts of the nervous system is smaller in proportion to the nerves themselves; that the respiratory process is far less active in proportion to the weight of their body; that, according to Prevost and Dumas, their blood, and according to Saissy, that of hybernating animals also, contains less coagulable matter; and, lastly, that birds and some Mammalia, the blood of which was found by Prevost and Dumas, to contain a larger quantity of red particles and coagulable matter, also have a higher temperature.

Effects of Heat and Cold.—The facts relative to winter and summer sleep are closely connected with the known depressing influence of a long-continued high temperature on the functions of the nervous system in man, and this is a very fit occasion for comparing the effects of heat and cold. Both may induce a disturbance of the excitability of the body, as well as irritation, inflammation, and sphacelus. The sudden and violent action of cold on warm animal tissues has a disorganising effect. Very cold bodies, when touched, produce a sensation of pain and then numbness. When the cold is more extreme, sphacelus or local death ensues. A slighter application of cold, by extracting the animal heat, produces symptoms of inflammation and irritation, from the effort which is made by nature to restore the balance in the part. A moderate degree of cold has at first an exciting effect. Thus cold water produces instantaneous reddening of the skin, as I have myself observed when bathing in the month of October; but this effect is only momentary, and the phenomena of disturbance of the internal organs from extraction of heat soon follow. Cold is sometimes used in this way, as a stimulant, to produce a temporary disturbance of the nervous system, which may be beneficial. In fevers with a hot dry skin, cold water often acts indirectly as a vivifying stimulant, and restores the action of the skin, as warmth does in parts suffering from cold. The secondary effects of continued cold are always depression of the powers of the nervous system. The gradual action of a high degree of cold by withdrawing a vital stimulus, induces in the human subject a state of torpor, and in hybernating animals that of hybernation; a too elevated temperature also depresses gradually the action of the nervous system, but probably by its producing a change of composition; and excessive heat with want of water, causes asphyxia in the sandy deserts, and gives rise to the summer sleep of reptiles and of the tanrec in hot climates.

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example, the chief chemical changes in the air are, as Dr. Edwards has found, brought about by means of the skin. Even in man himself, the skin is active in absorbing oxygen and giving out carbonic acid, and of course in contributing to the evolution of animal heat.

3. *Of the development of light in animals.*

It is now known with certainty that the *phosphorescence of the sea,*—the light visible in the waves, especially in the track of sailing vessels,—which has been observed as far south as 60°, arises from the presence of luminous animals in the water. These animals are in part Infusoria, in part Rotifera, in part Polypifera, in which it is chiefly the polypes themselves which are luminous; while many Medusæ, some Annelida, Mollusca, and Crustacea also contribute to the phosphorescence of the sea. It appears, that even the mucus and water which flow from these animals is sometimes luminous. Meyen* distinguishes three sources of phosphorescence in the sea:—1. Mucus dissolved in the sea-water: 2. Animals covered with a phosphorescent mucus. The production of light here appears to depend on the oxidation of the mucous covering of the animals, for when it has disappeared in consequence of a slight change produced in the surface, such as a stroke of the finger produces, it is quickly restored. 3. Animals possessing proper phosphorescent organs. Meyen examined particularly the *Pyrosoma atlanticum,* of which the light is very vivid, and of a greenish blue colour. As soon as the animals were touched by the net, used in catching them, they sank in the water and ceased to emit light. When one of the creatures, kept in water after capture, was touched, the light first appeared as very minute sparks, which issued from a dark, almost cone-shaped, body in the substance of each of the separate individuals forming the compound animal. This dark conical body is soft, and of a red-brown colour. It lies in each individual close behind the oral orifice, and somewhat in front of the respiratory organs, and is generally very close to the internal surface of the compound Pyrosoma. Its apex presents under the microscope from thirty to forty very minute red points.

Ehrenberg† also has observed many new facts which tend to clear away the obscurity which hitherto involved the subject. The first animal which he detected as phosphorescent was the *Polynoe fulgurans,* an annelide of the Baltic, in which the fulgent organs are two large granulated bodies like ovaries. Water of the Baltic sent to Berlin was still phosphorescent with these animals. The *Oceania hemispherica,* which measures more than an inch in diameter, presented an entire zone of luminous points at the circumference of its disk. These luminous points always corresponded to the thick bases of the great cirri, or to organs near them and alternating with them. No light issued from any other part of the body of these animals either during life or after death. From further observations Ehrenberg became more and more convinced that dead Infusoria do not emit light any more than fragments of dead fishes or mucus floating in the water. In the *Nereis cirrigera* (*Photocaris,* Ehrenberg), the light is given out by two fleshy cirri upon each of the feet. A flickering of a few sparks upon each cirrus was first seen; then the whole cirrus shone; and at last the emanation of light extended over the back, and the entire animal resembled a burning match. The mucus of the Photocaris adhering to the fingers, was likewise phosphorescent. Ehrenberg doubts whether the development of light is in any way connected with respiration, but believes it to have some relation to the sexual function. The faculty of developing light seems to him to be a vital function very similar to that of the development of electricity; when frequently excited, it becomes weaker, and is gradually lost for a time, and it has, moreover, an evident connection with the action of the nerves.

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* Nov. Act. Nat. Cur. vol. xvi. Suppl.

† Uber das Leuchten des Meers, Abhandl. der K. Acad. der Wissensch, zu Berlin, 1835. This paper contains also a complete historical account of the facts previously known.

The Naturalists of the Bonite* found the phosphorescence of the sea to be essentially due to the presence of organised beings. They observed that the small luminous Crustacea emitted, when irritated in any way and under some other circumstances, real jets of phosphorescent matter, which, at the moment of its being ejected by the animal, rendered the water luminous. Besides the different luminous Crustacea, Mollusca, and Zoophyta, the French naturalists observed very small yellowish bodies, which were endowed with a uniform phosphorescence. These bodies were motionless when viewed under the microscope. They varied in form; those observed near the Sandwich Isles were globular and transparent, with a yellowish point in the centre; those obtained at the Malacca Straits were slightly ovoid, reniform, and wholly yellow. Re-agents caused their phosphorescence to become at first more brilliant, after which it was insensibly extinguished. These bodies were sometimes so abundant as to make the surface of the sea for a great extent appear as if covered with a yellow powder.

The *luminous insects* are the *Elater noctilucus, phosphoreus,* and *ignitus;* the *Pausus sphærocerus, Scarabæus phosphóreus,* several species of Lampyris, and the *Scolopendra electrica.*† In the fire-fly (*Elater*), the principal sources of the light are two oval spots at the side of the thorax covered with transparent laminæ. Treviranus could discover no difference between the luminous substance and the fat of the body. In the glow-worms (*Lampyris nocticula* and *splendidula*) the light issues from the under surface of the last three abdominal rings, particularly from two whitish spots on the last ring; the ova of the Lampyris splendidula are also luminous, and it seems that the pupa and larva are not entirely without light. The opinion of Treviranus appears most probable; namely, that the light is derived from a matter containing phosphorus, which is formed under the influence of light, but, once formed, is in some measure independent of light. Several phenomena would lead us to believe, that luminous insects absorb light during the day, like the Bononian stones, and emit it in the evening: this was indeed the opinion of Carridori, Beccaria, and Monti, and is supported more especially by the circumstance that this absorption of light is evidenced by several mineral substances, such as sulphate of barytes mixed with sulphuret of barium, oyster-shell heated to redness with sulphur, &c., and also by several organic substances, when dried, such as seeds, flour, starch, acacia gum, quills, cheese, yolk of egg, muscle, tendon, isinglass, glue, and horn. But such an opinion does not accord with the observation of Todd and Murray, that glow-worms shine in the evening, even when they have been kept in the dark during the day; Macaire and Macartney, however, deny that this is the case.†

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* Comptes Rendus, 1838, i. 458.

† Treviranus, Biol. 5. 97.

Development of light in the higher animals.—There is no instance known of the development of light in any of the higher animals, except, perhaps, the phosphorescence of the ova of lizards, and that which has been sometimes observed in the urine. The supposed luminous property of the eyes of many Mammalia, particularly of the predacious animals, and more especially cats, and also of the eyes of oxen and horses, is now regarded as one of the superstitions of medicine. The luminous appearance of the eyes of some animals arises from the reflection of light from a brilliant tapetum which is devoid of black pigment; for which reason the eye of the white rabbit is especially brilliant, and the eyes of the Albino Sachs are said to have been luminous. Prevost† was the first to explain the phenomenon; he showed that it could never be seen in complete darkness, and is dependent neither on the will, nor on the passions; but is the effect of the reflection of light which enters the eye from without. Independently of Prevost, Gruithuisen, Rudolphi, Esser and Tiedemann have observed the same facts; and my own observations are coincident with theirs. The question has been finally decided by the observations of Hessenstein.‡ His experiments show that the eyes of animals, even when irritated, never appear luminous in perfect darkness, but that the admission of the smallest quantity of light, even of the light of the moon, is sufficient for the production of the phenomenon, which ceases, however, as soon as the external light is excluded. His observations on the reflecting white pigment of the eyes of carnivora, are very interesting.§

Some persons have imagined that the sensation of light produced by pressing the eye, was also owing to the emission of light. But it is a mere sensation like that of pain in the skin, and is produced by any irritation of the retina, from whatever cause, whether from chemical, mechanical, or electric stimuli, or from an internal organic cause. The flashes of light perceived when the retina is thus irritated are unattended with any emission of light, and are, therefore, never visible to any other person than the subject of them.*(*a.*)

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* Tiedemann, Physiol. i. 503.

† Biblioth. Britannique, 1810, t. xlv.

‡ In a good treatise, De Luce ex quorundam animalium oculis prodeunte, atque de Tapeto lucido. Jenæ. 1836.

§ See Anatomy of the Eye, in Chapter II. of the Section on Vision.

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* Compare my remarks on a medico-legal case, in which a person was said to have recognised a robber by the light produced by a blow on the eye. Müller's Archiv. für Anat. und Physiol. 1834, p. 140.

(*a*) Sir Henry Marsh, in a paper in the *Provincial Medical Journal*, (June, 1842,) after speaking of the elimination of light from certain vegetables and many of the inferior animals, details some cases of a similar production by the human subject. Two of these were phthisical persons, one a female, whose face, ten days previous to her death, was lighted up so as to give it "the look of being painted white and highly glazed; but the light danced about and had an extraordinary effect:" the other, a man, exhibited about him "a luminous fog, resembling the aurora borealis,"—to use the words of Dr. Donovan, whose patient he was. Dr. D. attributed the appearances which he witnessed in this last case, "to the presence of phosphorescent matter in the expiratory and perspiratory secretions." But, and the remark is an important one, Dr. Donovan adds, that the luminous appearances were not at any time visible to him on the person of the patient; the scintillations which he described were perceptible immediately over the head of his bed, on a wall composed of stone and clay mortar. The luminous fogs passed in streams through the apartment in which the sick man lay, and on one occasion Dr. Donovan fancied that he saw a meteor, like a falling star, suddenly pass through the house. Appearances of a similar nature, continues Dr. Marsh, are said to have been seen about the person of a woman named Pallister, who died some time ago in the neighbourhood of Hull, but no well authenticated accounts of the phenomena were procured.

In the case of the woman first mentioned, the light was seen for the first time during a night when there was a candle burning in the room, but it was perfectly shaded, so that none of its light could be shed on the face of the patient. Afterwards, however, the luminous appearance of the face was seen by the narrator, a friend of the patient, who sat up all night with her, when there was no candle in the room nor moon shining. The state of the system of the patient at this time was that of extreme exhaustion.

Doctor Stokes related to Dr. Marsh the fact of a cancer on the breast of a poor woman, a patient in the Meath Hospital, emitting a "luminous fluid" from all parts. The light was visible to him when standing twenty feet from her bed; and within a few inches of the ulcer, it was sufficient to enable Dr. Stokes to distinguish the figures on a watch dial.

SPECIAL PHYSIOLOGY.

BOOK I.

GENERAL ANATOMY.

SECTION I.

OF HISTOGENY, OR THE FORMATION AND DEVELOPMENT OF THE TISSUES.

Component Proximate Principles of the Tissues.

The proximate principles of the tissues are fibrin, albumen, gelatin, ozmazome, and fatty matter. Fibrin and albumen, the chief ingredients of blood, contain, in all, seven chemical elements, among which nitrogen, phosphorus, and sulphur are found. They contain also the earth of bones.

Chemical analysis, says Liebig, has led to the remarkable result, that fibrin, albumen, and casein, contain the same organic elements united in the same proportion, so that two analyses, the one of fibrin and the other of albumen, do not differ more than two analyses of fibrin or two of albumen respectively do, in the composition of 100 parts. We also learn that although in these two ingredients of blood the particles are arranged in a different order, as is shown by the difference of their external properties; yet in chemical composition, in the ultimate proportion of the organic elements, they are identical.

This conclusion has lately been beautifully confirmed by a distinguished physiologist (Dénis), who has succeeded in converting fibrin into albumen, that is, in giving it the solubility, and coagulability by heat, which characterise the white of egg.

Fibrin, albumen, and casein, besides having the same composition, agree also in this, that they dissolve in concentrated muriatic acid, yielding a solution of an intense purple colour. This solution, whether made with fibrin or albumen, has the very same re-actions with all substances yet tried. The group of these three principles is represented by *protein*, see note (*a*) to page 15.

As far, therefore, as our researches have gone, continues Liebig, it may be laid down as a law, founded on experience, that vegetables produce, in their organism, compounds of protein; and that out of these compounds of protein the various tissues and parts of the animal body are developed by the vital force, with the aid of the oxygen of the atmosphere and of the elements of water.*

Now, although it cannot be demonstrated that protein exists ready formed in these vegetable and animal products, and although the difference in their properties seems to indicate that their elements are not arranged in the same manner, yet the hypothesis of the pre-existence of protein, as a point of departure in developing and comparing their properties, is exceedingly convenient. At all events, it is certain that the elements of these compounds assume the same arrangement when acted on by potash at a high temperature.

All the organic nitrogenised constituents of the body, how different soever they may be in composition, are derived from protein. They are formed from it, by the addition or subtraction of the elements of water or of oxygen, and by resolution into two or more compounds.

This proposition must be received as an undeniable truth, when we reflect on the development of the young animal in the egg of a fowl. The egg can be shown to contain no other nitrogenised compound except albumen. The albumen of the yolk is identical with that of the white; the yolk contains, besides, only a yellow fat, in which cholesterine and iron may be detected. Yet we see, in the process of incubation, during which no food and no foreign matter, except the oxygen of the air, is introduced, or can take part in the development of the animal, that out of the albumen, feathers, claws, globules of the blood, fibrin, membrane and cellular tissue, arteries and veins, are produced. The fat of the yolk may have contributed, to a certain extent, to the formation of the nerves and brain; but the carbon of this fat cannot have been employed to produce the organised tissues in which vitality resides, because the albumen of the white and of the yolk already contains, for the quantity of nitrogen present, exactly the proportion of carbon required for the formation of these tissues.

The true starting-point for all the tissues is, consequently, albumen; all nitrogenised articles of food, whether derived from the animal or from the vegetable kingdom, are converted into albumen before they can take part in the presence of nutrition.

Fibrin has been examined hitherto only in the solid state; but by filtering fresh frog's blood, we obtain it in solution, and by allowing it, as it passes through the paper, to drop into a watch-glass which contains acetic acid, its coagulation is prevented; or if, in place of acetic acid, the glass contains solution of common salt, the fibrin either does not coagulate at all, or only in a very small proportion. In the same way the coagulation of the fresh blood of the frog is delayed for a very long time, though not entirely prevented, by adding to it a solution of common salt. It has been long known that certain salts, such as sulphate of soda and nitrate of potash, when added in some quantity to fresh human blood, have the property of preventing its coagulation. And this in some measure explains the action of the cooling salts on the blood in the treatment of inflammation; they produce some change in the fibrin, which counteracts the great tendency that it has in that morbid state to accumulate and coagulate in the vessels of the inflamed organ and on the surface of membranes after exudation.*

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* The experiment of Tiedemann and Gmelin, who found it impossible to sustain the life of geese by means of boiled white of egg, may be easily explained, when we reflect that a graminivorous animal, especially when deprived of free motion, cannot obtain, from the transformation or waste of the tissues alone, enough of carbon for the respiratory process. 2 lbs. of albumen contain only 3½ oz. of carbon, of which, among the last products of transformation, a fourth part is given off in the form of uric acid.

It has also been long known that a watery solution of caustic potash or soda prevents the coagulation of human blood out of the body. According to MM. Prevost and Dumas, the coagulation of the blood of the higher animals, when removed from the body, is prevented by the addition of as little as $\frac{1}{1000}$th part of caustic potash. If the *liquor sanguinis* of the frog's blood, while filtering, is made to drop into a watch-glass in which there is some *liquor potassæ*, the fibrin does not coagulate to a clot, but there are slowly formed in it very small flocculi, which it requires close inspection to discover. The production of these flocculi is still more evident when the watch-glass contains sulphuric ether, fresh ether being added in proportion as it evaporates. No globules or flocculi are produced in the *liquor sanguinis* by the action of liquor ammoniæ.

Fresh coagulated fibrin may be obtained for chemical analysis by washing the coagula which adhere to the twigs with which fresh blood has been stirred, or by merely washing the crassamentum. As thus obtained, it is specifically heavier than water, serum, or blood deprived of its fibrin; it sinks in all these fluids if it is free from air-bubbles. The following description of fibrin is borrowed from Berzelius:—

Coagulated fibrin when washed is white; by drying, it becomes yellowish, hard, and brittle, but not transparent, and loses three-fourths of its weight. It becomes soft again when macerated in water, but is not dissolved. It has no particular smell or taste. At the temperature at which it undergoes decomposition, it melts, puffs up, and burns, leaving a shining cinder, just as is the case with other substances which contain nitrogen. The cinder burns to gray-white, compact, semi-fused ashes, which amount to $\frac{2}{3}$ per cent. of the weight of the dried fibrin. The ashes are neither acid nor alkaline: after solution in muriatic acid they leave traces of silica, but they consist chiefly of phosphate of lime, some phosphate of magnesia, and a very slight trace of iron. The components of the ashes cannot be extracted by acids from the fibrin before combustion, and appear therefore to have entered chemically into the composition of the fibrin, and not to have been merely mixed with it. In the coagulated state, fibrin is insoluble both in cold and warm water, but by long-continued boiling in water its composition undergoes a change; it shrivels up, becomes hard, and falls to pieces on the slightest pressure. During this change no gas is developed; but the fluid becomes turbid, and is afterwards found to contain a newly formed substance derived from the components of the fibrin. The solution of this new substance has no similarity to solution of gelatin.*

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* See Dr. Burrows's Croonian Lectures, Medical Gazette, 1834.

Fibrin, coagulated albumen, casein, and colouring matter of the blood have this character in common, that they yield no gelatin by boiling in water. Fibrin has also, with some other substances, (but not albumen,) the property of decomposing peroxide of hydrogen by mere contact; oxygen being developed and water formed, while the fibrin remains unaltered. If the quantity of fibrin is large, heat is at the same time developed. It unites both with acids and alkalies, playing in the one case the part of a base, in the other that of an acid, or at least of an electro-negative substance. With concentrated acids it swells up, forming a transparent gelatinous acid substance; with diluted acids it forms a neutral compound, contracting considerably at the same time. The acid compound with the mineral acid is insoluble in water, the neutral compound is soluble; while both the neutral and acid compounds with acetic acid are soluble. The ferrocyanuret of potassium, when added to a solution of fibrin in acetic acid, throws down a precipitate: this is characteristic of fibrin, distinguishing it from cellular tissue, tendinous structure, and the elastic tissue of arteries. Albumen is acted on by the acids in the same way as fibrin. According to Caventou and Bourdois, fibrin, albumen, casein, and mucus, are dissolved by cold concentrated muriatic acid, and the solutions, if kept at a temperature of from 64° to 68° Fahr. acquire after twenty-four hours a beautiful blue colour; while this effect is not produced in the case of gelatin and the substance of tendons. If the fibrin used in this experiment had not been perfectly freed from the colouring matter, the fluid, instead of being blue, was purple or violet. Fibrin, albumen, and casein, also agree in being dissolved to a gelatinous mass by caustic potash and soda, without being, like horn, converted into a soapy substance. The gaseous elements of fibrin, according to the analysis of Gay Lussac and Thenard, and that of Michaelis,† are combined in the following proportions:—

	Gay Lussac and Thenard.	*Michaelis.*	
		Arterial Blood.	Venous Blood.
Nitrogen,	19·934	17·587	17·267
Carbon,	53·360	51·374	50·440
Hydrogen,	7·021	7·254	8·228
Oxygen,	19·685	23·785	24·065

Fibrin exists in solution in the chyle and lymph as well as in the blood, and the muscles and uterus contain it in the solid state. In the fibres of the arteries, however, there is no fibrin.

ALBUMEN.—The substance which remains after the extraction of the lactic acid and osmazome from the dried coagulum of the serum of the blood, is albumen. It is also an ingredient in lymph and chyle, in the white and yolk of the egg, (in the latter mixed with oil,) in the exhalations of the serous membranes, in the fluid of the cellular tissue, in the aqueous and vitreous humours of the eye, in the brain and nerves in combination with fat containing phosphorus, and in the contents of the Graafian vesicle of the ovary of Mammalia and man. Here we have to consider principally the albumen of the serum, and this in two states.

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* Berzelius, loc. cit. pp. 35, 36.

† See also Berzelius, loc. cit. pp. 34–47.—E. H. Weber, loc. cit. p. 83.

a. Albumen in the state of solution.—In the serum it is in combination with soda, forming what is called albuminate of soda. Berzelius does not believe that the albumen of the serum is held in solution by means of the soda; for the soda may be saturated with acetic acid, without any precipitate being produced. Stromeyer found that ten drops of distilled vinegar were necessary to neutralise half an ounce of blood. If serum or solution of albumen is evaporated at a temperature below 140° Fahr., the albumen is left dry and transparent, and is in that state soluble in water. At a temperature between 158° and 167° Fahr. the albumen coagulates, and it is then insoluble in water.

If serum is mixed with a large quantity of water, it no longer becomes solid by heat, but coagulates in globules, so as to form a milky fluid, which, however, when evaporated, yields coagulated albumen with the usual characters. Albumen is coagulated by the action of the galvanic battery, by alcohol, mineral acids, metallic salts,—for example, by salts of tin, lead, bismuth, silver, and mercury,—by chlorine, and by infusion of galls; and the same effect is produced on the albumen of the serum, according to the observations of Dutrochet and myself, by a very concentrated solution of fixed alkali;—for example, coagulation is produced when a small quantity of serum is mixed with a large quantity of liquor potassæ. White of egg, however, unless undiluted, is not coagulated by liquor potassæ. Liquor potassæ precipitates also the albumen of lymph and chyle. Acetic acid, which throws down casein and the gelatin of cartilage from their solutions, does not precipitate albumen. Albumen of the egg is coagulated by pure ether, which produces no precipitate in serum. This was first observed by Gmelin, and I have since seen it confirmed.

My experiments on fibrin in the fluid state as it exists in the blood have afforded me data for comparing it with albumen in a state of solution. Acetic acid produces no precipitate in serum, and none also in the solution of fibrin; thus the liquor sanguinis of frog's blood, if allowed to drop from the filter into acetic acid, does not coagulate. The neutral salts produce no precipitate in serum; and many of them —as the carbonates of potash and soda, nitrate of potash and sulphate of soda,—prevent the spontaneous coagulation of fibrin. Common salt has the same effect on the fibrin in frog's blood. Liquor ammoniæ produces no precipitate in the fibrinous fluid obtained by filtration from frog's blood, any more than in solution of albumen or in serum. Liquor potassæ precipitates the albumen from serum, and likewise precipitates in small flocculi the fibrin of liquor sanguinis allowed to drop from the filter into a watch-glass containing it. Ether produces no precipitate in serum, but the fibrin coagulates when the liquor sanguinis or filtered frog's blood drops into a watch-glass containing ether. The coagulation of fibrin by liquor potassæ or ether differs from its spontaneous coagulation, inasmuch as in the latter case a completely coherent coagulum is formed which is at first transparent and gradually becomes turbid or opaque, while in the artificial coagulation the fibrin takes the form of separate globules, as is often the case with albumen when coagulated. The principal differences between the solution of fibrin and that of albumen in the serum, are, that the former coagulates spontaneously, while albumen coagulates only under the action of heat or certain re-agents, and that the fibrin is precipitated by ether in the form of globules, while the albumen is not. Coagulated albumen and fibrin are readily distinguishable from coagulated casein, by the latter substance when coagulated by acids and alcohol being again soluble in water. Albumen, fibrin, and casein, however, have the common character of being precipitated from their solutions in acids by ferrocyanuret of potassium

If albumen in solution is mixed with acids or alkalies, the part which unites with the re-agent undergoes the same change as when it is coagulated, even although the re-agent does not precipitate it; thus it is precipitated from the solution in acetic acid when potash is added, and from the alkaline solution on the addition of acids, just as is the case with the colouring matter of the blood under similar circumstances.

If a small quantity of a metallic salt is mixed with serum, and a rather larger proportion of caustic potash added than is necessary for the decomposition of the metallic salt, the oxide is not precipitated, but remains in solution combined with the albumen. Berzelius, who mentions this, remarks that by this means metallic salts, or oxides, are absorbed from the intestinal canal or the skin, carried into the circulation, dissolved in the serum, and expelled with the excretions; and hence it is that after the continued use of mercury, we find the protoxide dissolved in the fluids of the body.* Would not the extremely intimate combinations of the metallic oxides with albumen be useful in medicine? Albumen of the egg or serum coagulates when mixed with concentrated solutions of earthy or metallic salts, and the coagulum contains the components of the salt. These coagulated combinations of albumen with salts also deserve a greater attention in medicine. Among the metallic salts already mentioned, the acetate of lead, and, still more, the bichloride of mercury, are remarkable as being the most delicate tests for albumen. Corrosive sublimate renders turbid a fluid which contains only $\frac{1}{2000}$th part of albumen in solution. From its great tendency to unite chemically with this salt, albumen is an antidote for it.

b. Albumen in the coagulated state, in which it consists of aggregated globules, has the same chemical properties as fibrin, and Berzelius knows no chemical test to distinguish them, except that coagulated albumen does not decompose the peroxide of hydrogen.

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* Autenrieth and Zeller, Reil's Archiv. viii.—Schubarth, Horn's Archiv. 1823 Nov. 417.—Cantu, Mem. d. Tor. 29, 1825.—Buchner, Toxicol. 538.

Their elementary composition also differs little, as is seen by comparing the analyses of albumen given by Gay Lussac and Thenard, Michaelis, and Prout, with those of fibrin already given.

	Gay Lussac and Thenard.	*Michaelis.*		*Prout.*
		Arterial.	Venous.	
Nitrogen,	15·705	15·562	15·505	15·550
Carbon,	52·883	53·000	52·650	49·750
Hydrogen,	7·540	6·993	7·359	8·775
Oxygen,	23·872	24·436	24·484	26·925

Berzelius found the proportion of the albumen to the other constituents in 100 parts of the serum of human blood to be as follows:—

Water,		90·59
Albumen,		8·00
Osmazome, with lactate of soda,	Extracted by alcohol,	0·40
Chloride of sodium,		0·60
Modified albumen—alkaline carbonate, and phosphate,	Extracted by water,	0·41
		100·00

Casein.—This principle is procured from milk. It requires no specific notice just now beyond that already given, of its general identity with fibrin and albumen.

Gelatin.—The new organic matters formed by the secretions—such as picromel, casein, mucus, &c.—being excluded from consideration, the blood will be found to contain the proximate elements of all the solid parts of the body,—namely, fibrin, albumen, osmazome, lactic acid, and fatty matter. The only exception is the gelatin or gluten which is obtained from tendon, cartilage, bone, serous membrane, and cellular tissue, particularly that of the muscles. Parmentier and Deyeux, and Saissy thought, indeed, that they had discovered gelatin also in the blood; but this was evidently an error. Gelatin is obtained from the parts above-mentioned by boiling water: its slight solubility in alcohol and cold water serve to distinguish it from osmazome. Its solution even in one hundred and fifty parts of hot water forms à jelly on cooling, which is a compound of the gelatin with water; this jelly is again soluble in boiling water, by which it is distinguished from fibrin and albumen. Gelatin is slowly soluble in acids and alkalies, and is precipitated by tannin, alcohol, bichloride of mercury, sulphate of platinum, chloride of platinum, and chlorine. It is not precipitated by the muriatic and acetic acids, acetate of lead, alum, sulphate of alumina, and sulphate of iron. The solution of gelatin in acids is not precipitated by ferrocyanuret of potassium. Some writers regard gelatin as a product of the decomposition of other animal matters in boiling, and in proof have adduced the observation of Berthollet, that muscular substance, which has ceased to afford gelatin by boiling, reacquires that property after undergoing putrefaction in a confined atmosphere, with development of carbonic acid.* It appears to me, however, that the arguments in favour of that opinion are insufficient, and there are many others opposed to it. The tissues above-mentioned alone yield gelatin by boiling; there must consequently be a peculiar matter pre-existing in them, and my recent investigations have shown that this matter varies in its properties according to the parts from which it is obtained. See the account of the chemical composition of the tissues to be given presently.

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* Consult Wienholt.—Meckel, Archiv. i. 206.—Berzelius, loc. cit. p. 661. The French translation, p. 703.

Osmazome, or animal extractive of Thouvenet, is soluble both in water and alcohol, whether hot or cold; it deliquesces in a damp atmosphere, melts when heated, and is precipitated from its solutions by infusion of galls. Osmazome is found by Gmelin to exist also in saliva, and in the pancreatic and gastric juices. Berzelius regards osmazome not as a peculiar substance, but as a compound of an animal matter with salts of lactic acid.

Fatty Matter.—It is most probable that fat is really contained in the fibrin, albumen, and colouring matter, and is merely extracted from it by the process of boiling in alcohol, for the chyle from which the blood is formed contains fatty matters in the free state, in the form of emulsion; and during the formation of the blood, these fatty matters of the chyle unite probably more intimately with the other animal matters. Chevreul has, by means of ether, separated from fibrin a fatty matter, analogous to that which we obtain from the brain, and, like it, chiefly remarkable for containing phosphorus in a combined state. Berzelius also is now of opinion, that the fatty matter is only extracted, not produced, by the analysis; and he is led to this opinion more especially from observing that the fibrin is not chemically changed by the extraction of the fat by ether or alcohol, and that after the usual small quantity of fat is separated, no more can be obtained by continuing the process. The fatty matter of fibrin is, according to Berzelius, in a saponaceous state, for its solution in cold alcohol reddens litmus paper; a proof that at least a part of it must be in the state of an acid, as is the case after the process of conversion of a fat into soap. Berzelius describes two modifications of the fatty matter of fibrin, and concludes with the remark, that it has great resemblance to the acid salts of stearic and elaic acids with potash, described by Chevreul, except in its greater solubility in ether and alcohol. According to Chevreul, the fatty matter in fibrin amounts to 4 or 4½ per cent. Lecanu found a crystallisable fatty matter, and an oily matter in the blood; of the former there were from 1·20 to 2·10 parts, of the latter from 1 to 1·30 part in 1000 parts of serum. Boudet[*] confirms Gmelin's statement that the blood also contains cholesterine.

When free, uncombined, fatty matter exists in the blood in unusual quantity, the serum is rendered milky by globules of fat floating in it; this is frequently observed in young animals, and more rarely in adult human beings.[†]

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[*] Essai Critique et Expérimental sur le Sang. Paris, 1833.

[†] See Dr. Babington, Med. Chir. Transact. vol. xvi.—Dr. Trail, Edinb. Med. and Surg. Journ. vol. xvii.—Dr. Christison, ibid. xxxiii.—M. Lecanu, Ann. de Chimie et de Phys. t. xlviii.

All kinds of fat are remarkable for the small quantity of oxygen, and the preponderating quantity of carbon, which enter into their composition. It is also remarkable that the fatty matters,—elaine and stearine,—which occur in the body in the free state, always combined one with the other, contain absolutely no nitrogen. Elaine and stearine are soluble in ether and hot alcohol, and the elaine remains dissolved in the alcohol even after it has cooled.

	Stearine.	Elaine.
Oxygen,	9·454	9·548
Hydrogen,	11·770	11 422
Carbon,	78·776	79·030

Other fatty matters—for instance, that of the blood—are combined with other animal substances; they crystallise in part when exposed to the cold, contain nitrogen, and cannot be converted into soap. The fatty matters of the blood and brain contain phosphorus also. Fatty matters of this kind occur in a combined state in the blood, in cerebral and nervous substance, in the liver, and perhaps in some other parts.

CHAPTER I.

Histogeny—The formation and development of the animal tissues.

The proportion in which the proximate principles, described in the last chapter, severally enter in the composition of the tissues will presently be stated, after the experiments and views of Schleiden and Schwann have been noticed. But, before speaking of these as relates to the animal organism, it may be well to repeat a few of the leading propositions of Schleiden on the structure of the newly formed tissues of plants. All these seem to take their origin from *gum*. This substance is in some instances directly supplied by the operation of the formative processes upon the nutritive materials derived from without. More frequently, however, it has passed through the intermediate condition of *fecula* (starch) or one analogous to it. Starch in the plant appears to supply the place of animal fat, in its being superfluous nutritive matter deposited for future use. Schleiden specifies the large cell or embryonal sac of the unimpregnated ovule (in which the albumen is afterwards formed,) and the end of the pollen tube, (from where the cells of the embryo itself are developed,) as the points in which the process of organisation may be observed most easily and clearly. At both these places the fluid is at first homogeneous and transparent; but minute granules, such as those found deposited in the cells of plants containing fecula, soon originate in it; and it then becomes opalescent, or even opaque through the presence of a large mass of granules. Single, larger, more sharply defined granules are now evident in this mass; and very soon afterwards they present a regular form, and increase considerably in size, apparently from the coagulation of the minute granules round the large ones. From these bodies the cells take their origin. When the cytoblasts, increasing separately in the gummy fluid, have attained their full size, the formation of the cell commences.(*a*)*

Modern vegetable Physiologists had already arrived at the result that the different tissues of plants, such as cellular tissue, woody fibre, ducts and spiral vessels are all originally developed from cells. The mode of formation of these cells has been explained by Schleiden.† He has shown that they are produced from the "nuclei" of Robert Brown, and hence he calls these bodies "cytoblasts" [κύτος a cell, βλαστὸς a germen]. The cytoblast is generally of a yellowish colour, and internally of a granular structure. In its interior Schleiden has detected a second nucleus (nucleolus) called by him the nucleus corpuscule, which sometimes resembles a mere spot, at other times a hollow globule. The cytoblasts are developed in a mass of mucous granules contained within previously existing cells. As soon as they have attained their full size, a delicate transparent vesicle rises upon the surface of each. This is the young cell, which at first bears the same relation to the flat nucleus as the watch-glass bears to a watch. When the cell has increased in size the cytoblast appears merely as a solid body included in the wall of the cell. The layer which now covers the cytoblast on the side towards the interior of the cell is extremely delicate,—indeed, seldom to be recognised by the eye,—and it soon becomes wholly absorbed, while the cytoblast itself disappears at the same time. The newly developed cells lie free in the cavity of the parent cell, and, as they grow and exert reciprocal pressure against each other, assume the polyhedral form.

The following are the more important observations of Schwann‡ respecting the cells of animals and the agreement of animals and plants in their ultimate structure.

In the chorda dorsalis, the cellular structure of which I had myself pointed out long since, Schwann first discovered the nuclei or cytoblasts. Each cell of the *chorda dorsalis* of *Pelobates fuscus* has its disk-like cytoblast lying at the inner surface of the wall of the cell; and in this nucleus there is seen one, rarely two or three, clearly defined spots. In the cavity of the cells young cells are developed, as in plants.

Cartilages also are, according to Schwann's observations, composed entirely of cells, when first formed. The cartilaginous branchial rays of fishes at their apex are composed of small polyhedral cells, lying in close contact with each other, and having very thin

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(*a*) The preceding paragraph and the whole arrangement of this Book, together with pages 97–8 from Liebig, are introduced by the American editor, who believes that a view of the formation, distribution, and general properties of the tissues, ought to precede an inquiry into the functions of the several organs, which are in various proportions composed of these tissues.

* Brit. & For. Med. Rev. Vol. IX.

† Müller's Archiv. 1838, p. 137.

‡ Froriep's Notizen, 1828, No. 91, 102, 112. Schwann, Mikroscopische Untersuchungen über die Ueber-einstimmung in der Structur und dem Wachsthum der Thiere und Pflanzen, Berlin, 1838. A review of this work with a copious abstract of its contents is contained in the 9th volume of the British and Foreign Medical Review.

walls. These cells have rounded granular nuclei. Towards the middle of the branchial ray the septa between the cavities of the different cells formed by their walls, gradually become thicker. Nearer to the root or base of the branchial ray the walls of the contiguous cells can no longer be distinguished from each other, and the mass appears to be formed of a homogeneous substance containing small cavities; but around some of the cavities a circular line can be distinguished which indicates the boundary of the wall of the cell, and proves that the whole mass is not formed by the thickened walls of the cells, but that a real intercellular substance also exists. Even while the walls of the cells are still in contact with each other, this intercellular substance is present, at that time appearing here and there like a triangular space between three contiguous cells. In this form of cartilage the process of development consists partly in the thickening of the walls of the cells and partly in the production of an intercellular substance. In higher vertebrate animals the thickening of the walls of the cells is not observed, and the principal mass of the future cartilage appears to be formed by the intercellular substance in which the cells with the younger cells within them are included. The development of cells in the manner of the cells of plants has been observed by Schwann in the branchial cartilages of Pelobates fuscus, in which some cells contain mere nuclei; others, nuclei with small cells developed upon them and scarcely larger than themselves; others, again larger, fully formed cells. So that here all the stages of the development of a cell are present. The process of the development of cartilage seems to be independent of blood-vessels and to be wholly analogous to the process of growth in vegetable tissues. How the canals radiating from the corpuscules of ossified bone are developed is not known. Two hypotheses are proposed by Schwann. If the osseous corpuscules are the cavities of cells, the thickened walls of which have coalesced with each other and with the intercellular substance so as to form the mass of the cartilage of the bone, then the radiating canaliculi must be regarded as canals extending from the cavities of the cells through their thickened walls, and would be analogous to the pore-like canals of some vegetable cells. But if the osseous corpuscules are the cells themselves and not merely their cavities, the whole substance between the corpuscules being intercellular substance; in this case the canaliculi will probably be radiating prolongations of the cells extending into the intercellular substance. According to the latter view, which Schwann regards as the more probable, the canaliculi would correspond to the processes given off from some cells of plants.

Besides the formation of young cells in the cavities of previously existing cells, Schwann has observed their development in the exterior of other cells in a structureless substance, the cytoblastema. In this case also the nucleus generally appears to be first formed and the cell to be afterwards developed around it. In many animal tissues the new cells are formed on the exterior of the earlier cells. In the one case the cytoblastema exists in the interior of the cells already existing; in the other it is external to them.

Schwann arranges the tissues of the animal organism, according to the mode of their development, in five classes:

I. Isolated independent cells which either float free in a fluid, or if deposited in contact with each other are still unconnected and movable.

II. Independent cells arranged so as to form a continuous membrane.

III. Tissues formed of cells, the walls of which have coalesced, while their cavities remain distinct.

IV. Fibre cells,—cells which have become elongated in different directions and resolved into bundles of fibres.

V. Cells, both the walls and the cavities of which have coalesced, so as to form tubes.

To the *first class* belong the corpuscules of the blood. The vesicular nature of these bodies was observed by C. H. Schultz. Their nucelus, as Schwann remarks, remains attached to the inner surface of their membranous parietes when they are rendered turgid by the action of water. The red colouring matter of the corpuscules is to be regarded as the contents of the cells. The lymph corpuscules, the globules of mucus and those of pus belong to the same class. They are all nucleated cells.

To the *second class* belong the horny tissues, the pigment membranes, and the tissue of the crystalline lens.

1. *Epithelium.*—Generally composed of round cells, to the inner surface of whose parietes a nucleus containing one or two nucleoli is attached. When united into a membrane they are polyhedral. In the epithelium of the skin of a frog Schwann saw two nuclei in one cell, and also a nucleated epithelium cell within another larger cell, a fact which Henle has not observed in Mammalia. The epithelium cells, at first globular, undergo modifications of form in one or two directions. Either they acquire the form of perpendicular cylinders, as in the epithelium of the intestinal mucous membrane, described by Henle; or they become flattened into laminæ, which have the nucleus in the middle of one surface and which sometimes are elongated or riband-shaped, as in the epithelium of blood-vessels according to Henle. In the latter case it is observed that the young cells are found beneath the older ones, and are at first globular, but become more and more flattened as they approach the free surface of the epithelium.

2. *Pigment cells.*—These have a nucleus at one part of their parietes, which produces the well known white spot in the middle of some pigment cells. The nucleus has usually one or two nucleoli. Many pigment cells in the process of their growth send out hollow fibre-like processes in different directions, so as to become stellate cells.

3. *Nails.*—The nail of a fully developed human fœtus consists of laminæ lying horizontally one upon the other. These laminæ become less and less distinct at the inferior surface of the nail, in proportion as the part examined is nearer to the root of the nail which is inserted into the fold of the skin of the finger; and the posterior

half of this portion of the nail presents nothing of a laminated structure, but consists merely of polyhedral cells with distinct nuclei. Laminæ of the nail treated with acetic acid separate into scales in which an indistinct nucleus can in very rare cases be observed. The polyhedral cells of the root of the nail must become flattened into these scales, and the nail ought consequently to become thinner towards its free margin. This is probably prevented by the formation of laminæ of epithelium at the under surface of the nail. The horny tissue of the hoofs of animals also consists, in the fœtus, entirely of cells.

4. *Feathers.*—The medullary substance of feathers is composed of polyhedral cells. In the young feather a nucleus is visible in the wall of each of these cells. The cells are developed around small nuclei which lie in great number in a finely granular matter. This formation of new cells takes place not in old parent cells but near the surface of the vascular matrix of the feather, which affords the cytoblastema. Some of the nuclei contain nucleoli. The fibres of the cortical part of the shaft of the feather are produced from large band-like epithelium cells which contain nuclei and nucleoli. These cells become resolved into several fibres, while all trace of the cell disappears. The barbs of the feather are themselves miniature feathers; the secondary shafts have the same structure as the main shaft, while the secondary barbs or barbules in their turn consist at first of nucleated cells applied to each other by their edges.

5. *The crystalline lens.*—The fibres of the crystalline lens are developed from the cells first observed by Werneck. In the lens of a chick after eight days' incubation there are as yet no fibres, but merely pale round cells, some of which contain a nucleus. In lenses further developed, some of the larger cells contain one or two smaller cells in their interior. In embryo pigs, measuring 3½ inches in length, the greater part of the fibres of the lens is already perfect; but a part is still not completely formed; and there are besides many round cells which are about to undergo their metamorphosis. The perfect fibres compose a nucleus in the centre of the lens. The next fibres are seen to be tubular prolongations of globular cells. The dentated borders of these cells, like those of some vegetable cells, are formed subsequently.

Class III.

1. *Cartilages.*—Their structure and mode of development have already been described.

2. *The teeth.*—The enamel of a tooth not yet fully formed retains the same form and structure after it has been treated with dilute acid. The inner surface of the enamel membrane which envelopes the crown of the tooth is formed of short hexagonal fibres, placed perpendicularly, so that each fibre of the enamel membrane corresponds to a fibre of the enamel. These fibres of the enamel membrane appear to be elongated cells. In the fresh state they contain a nucleus with nucleoli. Beneath these prismatic fibres of the enamel membrane is a layer of round cells which probably represent the primary

condition of those fibres. The true enamel fibres probably separate from the enamel membrane, coalesce with the enamel already formed, and at the same time become impregnated with calcareous salts. The substantia propria, or ivory of the tooth, is formed of fibres, between which the dental tubuli run. The pulp of the tooth at its surface consists of cylindrical cells, which contain nuclei with nucleoli. The interior of the pulp is composed of round nucleated cells. Schwann conjectures that the fibres at the surface of the pulp are in successive layers added to and converted into the growing dental substance, the pulp being as it were converted into cartilage, and then ossified. If this be the case, the processes of chondrosis and ossification must advance by successive strata. The researches of Mr. Owen (Ann. des Sc. Nat. 1839, Oct. Odontography, pt. i.) and those of Mr. Nasmyth (Three Memoirs on the Development and Structure of the Teeth and Epithelium, London, 1841) confirm this view.

Class IV.

1. *Cellular tissue.*—In the development of cellular tissue there first appears a structureless cytoblastema, in which round nucleated cells are subsequently formed.(*a*) These cells become transformed into spindle-shaped bodies, which have in their interior, but attached to their wall, a round or oval nucleus, while this nucleus in its turn includes one or two dark points (nucleoli). These elongated cells become more and more drawn out at their extremities, and give off fibres, which are sometimes branched; and at length become resolved at each end into a fasciculus of extremely delicate fibrils. The division of the fibre-like prolongations of the cells into more minute fibrils gradually extends towards the centre of the cell, so that at a later period the fasciculus of fibrils proceeds immediately from the body of the cell. Lastly, the division into fibrils takes place even in the situation of the nucleus of the cell, and then the cell becomes wholly resolved into a fasciculus of fibres, upon which the nucleus lies. The fibres are probably tubular.

The cells of adipose tissue which are found even in the cellular tissue of the fœtus, present at first a distinct nucleus attached to their membranous wall. When the wall of the cell is thin, the nucleus forms a prominence above the surface of the fat globule contained in the cell. When the wall of the cell is thick, the nucleus is entirely included in its thickness. The nucleus contains one or two nucleoli. The fat cells in the cranium of a young fish (Plötze) sometimes have each two nuclei which bear the same relation to the membranous wall of the cell. In the cellular tissue of the fœtus, a third kind of cells is met with. These are round and pale; each has a nucleus with one or two nucleoli attached to its wall; they do not become elongated into fibres, contain no fat, but are filled with granules; and this deposit of granules is first formed about the nucleus.

The cellular tissue of the fœtus, when submitted to boiling, yields no gelatin; but in its place a substance which resembles pyine, except in the particular that the turbidity produced in the solution

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(*a*) See note to page 113.

by hydrochloric acid is removed by the addition of an excess of the acid.

2. *Tendinous tissue.*—The fibres of tendinous tissue are formed from cells, in the same way as those of cellular tissue.

3. *Elastic tissue.*—The middle coat of the arteries in embryo pigs, six inches in length, contains numerous isolated cells, some of which are globular, and some have an oblong form, while others give out two or more branching processes of various length. At the inner surface of the wall of each of these cells lies the usual nucleus with one or two nucleoli. In addition to the cells thus variously modified, fully developed elastic tissue is also present. The branching fibres of elastic tissue, which, according to Purkinje, are hollow tubes, appear to be formed from the cells just described.

Class V.

In the development of the tissues of this class there are first formed independent cells, which are either round or cylindrical, or have a stellate form. In the former case the primary cells arrange themselves in longitudinal series, their walls coalesce at the points of contact, and the septa thus formed between the cavities of the different cells are subsequently absorbed, so that in place of several primary cells one secondary cell is produced. This secondary cell now continues to grow as the simple cells grow. In this way the fibres of muscles and nerves appear to be developed. In the case of the stellate primary cells the radiating processes of contiguous cells unite, and their walls becoming absorbed at the points of union, a network of communicating canals is formed. This seems to be the process by which capillaries are developed.

1. *Muscles.*—Valentin had observed that the primitive fasciculi (fibres) of muscles are formed by granules arranging themselves in a linear manner and coalescing; but that the primitive fibres (fibrillæ) are produced by the subsequent division of the primitive bundle. Schwann has remarked that the primitive fasciculi in the muscles of a fœtal pig, measuring 3½ inches in length, present a dark border—and a middle, more transparent part, probably a cavity. In this more transparent part he perceived, besides some small granules, a series of larger oval flat bodies, which appeared to be the nuclei of cells, and frequently contained one or two smaller corpuscules,—their nucleoli. These nuclei lay at pretty regular distances from each, in the thickness of the cylinder, but external to its axis. In muscles more advanced in development, the primitive fasciculi present no indication of a cavity; but the nuclei remain visible for a long period, frequently producing slight prominences on the surface of the cylinders. According to recent observations of Rosenthal the nuclei are still present in the muscular fibre of adult animals. The proper substance of the muscular fibres is produced by a deposit taking place within the tube. The structureless sheath of the primitive muscular fasciculus, which I observed long since in insects, appears to be the remains of the tube formed by the united walls of the primitive cells.

According to the late observations of Valentin,* there are first visible in the blastema of muscle nuclei with nucleoli, which soon become surrounded by extremely delicate cells. These cells assume an oblong figure and arrange themselves in linear forms like filaments of confervæ. On the inner surface of the membranous walls of the tubes or secondary cells formed by the coalescence of the primary cells, longitudinal striæ or fibres are deposited, while the septa dividing the tube into compartments are absorbed. The muscular fasciculus then has the form of a tube, with proportionally thick walls which are composed of perfectly transparent longitudinal fibrils. The nuclei of the primary cells are contained in the cavity of the tube.

2. *Nerves.*—Each entire nervous fibre is to be regarded as a secondary cell, formed by the coalescence of a series of primary nucleated cells. Schwann is of opinion that the white substance of the nervous fibre, which forms a tube around Remak's band-like axis of the fibre, or the cylindrical axis of Purkinje, is a secondary deposit on the inner surface of the membranous wall of the secondary cell. He finds that the white substance of each nervous fibre is invested externally by a peculiar structureless sheath like that of the primitive muscular fasciculi. This membranous sheath can be distinguished as a transparent border external to the opaque white substance of the fibre. Its defined outline is adverse, Schwann remarks, to the view of its being composed of cellular tissue. In perfectly formed nervous fibres Schwann sometimes perceived here and there at the side of the fibre a nucleus which lay included in the transparent border formed by the membranous sheath. In the grey nervous fibres no substance is formed.

In the substance of the brain of young embryos Valentin observed cells on the outer surface of which a granular mass was gradually deposited. These cells subsequently became nuclei; and their former nuclei became nucleoli; while the granular matter deposited around them formed the mass of the ganglionic globules which were thus developed. Valentin has also observed, that, after the development of nervous fibres, nuclei, elongated fibre-cells, and fully developed fibres of cellular tissue are formed around them.

Schwann's discoveries are to be ranked amongst the most important steps by which the science of physiology has ever been advanced. They afford the basis for a general theory of vegetation and organisation which it had hitherto been impossible to frame. Valuable observations had been made in all parts of physiology, and some branches of the science had been brought to a high state of perfection. But as regards the fundamental principles on which all should rest, these it must be confessed were either very unstable or entirely wanting, and hence the slight connection which seemed to subsist between different important observations in parts of the science which were far advanced. These fundamental principles are now attained. Schwann himself has pointed out with equal lucidity and acuteness the general conclusions which are to be deduced from the observations of Schleiden and himself, and has framed from them a theory of the organisation and vegetation of organised beings. It is not possible to give in this work more than the principal features of his theory.

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* Müller's Archiv. 1840, p. 197.

There is one common mode of development observed in the formation of the most different elementary tissues of plants and animals, and that is the development from cells. In a pre-existing structureless substance, which may be situated either within or on the exterior of cells already formed, new cells are developed in a manner regulated by determinate laws, and these new cells undergo various modifications and transformations by which they are converted into the elementary organic tissues. In every tissue the new cells are formed only in those parts to which new nutritive matter has direct access. On this alone depends the difference subsisting between the vascular and non-vascular tissues. In the former, the nutritive fluid, the liquor sanguinis, is distributed through every part of the tissues, and hence new cells are formed through its substance.(*a*) In the non-vascular tissues, on the contrary, the nutritive fluid has access to one surface only, as in the case of the epidermis. Hence in cartilages, also, when they are destitute of vessels the new cells are formed only at their surface, or to a slight depth, namely, as far as the liquor sanguinis, their cytoblastema, penetrates. The expression, growth by apposition, is correct, when understood to signify the development of new cells, and not the growth of those already existing: for in the epidermis new cells are formed only at the inferior surface of the membrane, whilst in the vascular tissues the new cells are developed in the whole substance of the tissue. In both cases, however, the cells themselves grow by intus-susception. Cartilage is at first destitute of vessels, and the new cells consequently are formed only in the vicinity of the external surface. But after vessels have extended into the medullary canals, the formation of new cytoblastema and new cells can proceed not only on the surface of the bone but also around each of these canals. This explains the structure of the cartilage of bone, the lamellæ of which are concentric, partly around the whole bone, and partly around the medullary canals. The process by which the primary cells are formed is the following. The cytoblastema, which is at first struc-

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(*a*) The researches of Dr. M. Barry, on the corpuscles of blood, (*Philosophical Transactions*, 1840 and 1841,) carry us a step further back in histogeny, by rendering it extremely probable, that these blood corpuscles, or globules as they have been not very accurately termed, are the nuclei or cytoblasts of the primordial cells from which all the tissues originate. Dr. Barry says, that he has found every tissue hitherto examined by him, "to arise out of corpuscles having the same appearance as the corpuscles of the blood." This remark is intended to apply to *Epithelium* and *Pigment cells*, *capillary vessels;* the *elements of*, *respectively*, *cellular tissue*, *cartilage*, *muscular tissue*, *nervous tissue*, *crystalline lens*, *the chorion*, *ovulum*, *spermatozooa*, and *the pus globule*. One of the best examples, which presented itself to Dr. Barry, of the conversion of blood corpuscles into organised tissue, was in the formation of the crystalline lens. He believes, also, that the resemblance between the primordial cells of the cellular tissue and the corpuscles of the blood is quite clear.

tureless or only finely granular, presents after a time round corpuscules. These corpuscules are in their earliest recognisable condition the nuclei of cells, around which cells are subsequently to be developed. The nucleus is granular, and may be either solid or hollow. The part of the nucleus first formed is the nucleolus. Around this there is deposited a layer of fine granules. The nucleus thus formed increases in size, and then the cell is developed around it by the deposition of a layer of substance different from that of the surrounding cytoblastema. This layer has at first no defined outline; but when it has become consolidated into a membrane, it expands by the continued addition of new molecules in the interstices of the old ones. It thus becomes removed from the surface of the nucleus, which remains attached to one point of the wall of the cell. This formation of the cell around the nucleus is only a repetition on a larger scale of the process by which the nucleus was formed around the nucleolus. The membranous wall of the cell differs in its chemical properties in different kinds of cells, and even in the same cells it varies in chemical composition at different periods of its growth. Thus the walls of vegetable cells, when first formed, are, according to Schleiden, soluble in water, which is not the case with the cells which are perfectly developed. The matter contained in the cells varies in a still greater degree; for example, it is in one case fat, in another pigment. In a cell which is at first perfectly transparent a granular deposit may gradually appear, its formation commencing around the nucleus; or, on the other hand, a granular deposit contained in a cell may be gradually dissolved.(*a*)

(*a*) The different ways in which the metamorphosis of granular nuclei takes place, are well expressed by Valentin.—*Wagner's Physiology*, p. 214—21.

I. The nuclei with their nucleoli, which at an earlier stage are free, surround themselves with a clear cell, which, however, soon dissolves, so that the nuclei swim about as characteristic corpuscles in the fluid, and as such advance in their individual development. In the normal orgasm, this is what happens in regard to the blood, and probably also to the lymph. The blood-globules are not cells, but nuclei. These nuclei are in fact nucleoli.

II. The nuclei surround themselves with cells which are permanent, but various metamorphoses of both the nuclei and cells ensue, according to the individual character of the tissues and the parts which they go to compose.

III. The cells exhibit metamorphoses, which in point of form are in all respects analogous to those observed during the formation of the wood, and indeed of the pores in plants.

IV. The cellular element is extremely distinct in the earliest periods of its formation, but a secondary product obscures it, or even causes it to disappear entirely, as in the development of adipose tissue or globules of fat in a transparent cell.

V. The nuclei surround themselves with extremely delicate cells, and about these a peculiar substance is deposited, which in its capacity of rapid growth, soon forms the larger portion of the tissue, and in which, as in all other intercellular masses, new nuclei and cells may be produced. Examples of this are furnished in the *imposed globules of the central and peripheral portions of the nervous system.* The process of development here is best observed in the grey substance of the superficies of the hemispheres.

VI. The cells exhibit a very high degree of productive or procreative power. New nuclei are perpetually arising within them, and these surrounding themselves with cells, we have finally cell within cell, like a nest of pill boxes; abundance of

CHEMICAL COMPOSITION OF THE ORGANISED TISSUES.

1. *Tissues with an albuminous base.* (*a*)—To which belong the brain and nerves, the muscles, glands, and mucous membranes.

These tissues yield no gelatin by boiling, which moreover produces little change in them; the cellular tissue which enters into their composition can alone be converted into gelatin. The different modifications of albuminous bodies are not, at present, well understood. We are acquainted with albumen only in the more restricted sense, and with fibrin; and the properties of these substances have been described in the chapter on the chemical analysis of the blood. The ferrocyanide of potassium throws down a precipitate from the acetic acid solution of albuminous bodies, by which character these are distinguished from the following.

2. *Tissues which yield gelatin by boiling.*—To these belong,—1, the cellular tissue; 2, serous membranes; 3, tendinous tissue; 4, skin; 5, one kind of contractile tissue; 6, cartilage; 7, bone; and, 8, elastic tissue including arterial tissue. The animal matter which forms their basis either dissolves wholly into gelatin, or they continue to yield this substance for some time when submitted to long boiling. Some tissues, such as cellular and serous membranes, and bone, even after a few hours' boiling, yield a large quantity of gelatin; others, as cartilage and skin, yield but little of this substance even after fifteen or eighteen hours' boiling; while several days are required to extract it in small quantity from other textures, such as elastic tissues. The ferrocyanide of potassium produces no precipitate in the acid solution of these textures which yield gelatin.

The cellular tissue, the contractile tissue of the tunica dartos, the tissue of the serous membranes, the tendinous or fibrous tissue, and the tissue which forms the basis of the skin, yield the common gelatin

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intercellular substance is at the same time deposited betwixt the parietes of the cells, and these two elements blended together compose the elementary mass, the cells with their products the nuclei and nucleoli, the proper and peculiar corpuscles. *Cartilage* is formed in this way; and cartilage-corpuscles pass immediately into *bone-corpuscles;* clear first, they become more opaque by degrees.

VII. The cells are tesselated or spread out into a membrane, in the manner of a piece of pavement; then granular nuclei lie in the middle. The parietes of the cells blend into a transparent simple membrane, whilst the nuclei are more and more absorbed, becoming constantly paler, until at length they are no longer recognisable. To this arrangement may be referred the *hyaloid* membrane and the *inner membrane of the blood-vessels.*

VIII. The cells and the nuclei arrange themselves in longitudinal lines; the cell-walls coalesce in lines, and at the cost of nuclei, form themselves into fibres. It is thus that the *cellular membrane, the elastic tissue, muscular tissue, fibres of the crystalline lens, and primary nervous fibre are formed.*

The universal primitive form of every tissue is therefore the *cell,* which itself is preceded by the *nucleus* as mediate, and the *nucleolus* as immediate products of the formative power. Cells and nuclei seem to stand in mutual and relative opposition, so that generally, perhaps invariably, the one is evolved at the expense of the other. After these transitive stadia are accomplished, the tissue attains individuality according to general character and the place it occupies in the system.

(*a*) Regarding, as we may now do, albumen and fibrin as modifications of the same principle, the term *albuminous* will serve to include the tissue hitherto spoken of as *fibrinous,* viz. the muscular.

or glue, *colla*, which is precipitated by tannin, chlorine, corrosive sublimate, and alcohol; but not by alum, acetic acid, acetate of lead, and sulphate of alumen. The precipitate thrown down by alcohol is again soluble in hot water.

The peculiar substance which I have described as the base of the permanent cartilages, agrees in many points with the ordinary gelatin, but differs from it in the following particulars. It is precipitated by alum, sulphate of alumen, acetic acid, and acetate of lead. The precipitate produced by alum is redissolved on the addition of an excess of the reagent; that thrown down by acetic acid is not redissolved by the addition of more acid. Casein is likewise precipitated by the same reagents as the gelatin of cartilage or chondrin; but casein does not form a gelatinous mass when its solution cools, and when thrown down by alum, it cannot be redissolved by an excess of that substance, while the precipitate which acetic acid produces is redissolved on the addition of more acid.

The cartilages are divisible into four classes:

a. Cartilages containing peculiar corpuscules.—The greater number of the permanent cartilages, and also the cartilage of bone before ossification, are composed of a semi-transparent, indistinctly fibrous tissue, containing in its substance numerous microscopic corpuscules generally of a flattened form, in the interior of which again there is often a nucleus or several granules. All the cartilages of this kind, namely, the costal cartilages, the majority of the cartilages of the larynx, those of the trachea, of the nose, and of the Eustachian tube, the articular cartilages, and the cartilage of bone before ossification, yield by boiling, according to my observation, the substance which I have named *Chondrin*, in place of the ordinary gelatin.

b. Chondrinous fibro-cartilage.—The cornea consists of three layers besides the delicate layer of epithelium which invests its free surface. The most superficial layer is rendered by hot water immediately of a snowy-white colour; the most internal lamina is the aqueous membrane, which is attached to the *lamina fusca* of the sclerotica; the middle layer, which constitutes the chief substance of the cornea, is formed of an interlacement of bundles of bright fibres without any intermixture of corpuscules. This is, according to my observation, reduced wholly to chondrin by boiling.

c. Spongy cartilages; their structure was discovered by Miescher. The cartilages of this kind are the yellowish cartilages of the external ear, the epiglottis, and the *cartilagines Santorinii et Wrisbergii* of the larynx. They are yellow, and contain none of the corpuscules of Purkinje, but are throughout of a spongy texture, having large cells. After being submitted to boiling during several days, they yield an extract in extremely small quantity, which does not form a jelly, but the chemical properties of which agree with those of chondrin; while the preceding cartilages dissolve within the space of fifteen or twenty hours into a chondrin which gelatinises on cooling.

d. Ligamentous cartilages.—These are interarticular cartilages, the intervertebral cartilages, the cartilages of symphyses. The substance which they yield by boiling is not chondrin, but gelatin entirely similar to that of tendons. They are constituted wholly of fibres, and contain none of the corpuscules of the first kind of cartilages. The tarsal cartilages of the eyelids, which are likewise fibrous, have not at present been examined with reference to their chemical composition.

The animal matter or cartilage of bone is composed of gelatin. It is remarkable that the cartilage of bone before ossification yields only chondrin when boiled, but after ossification it affords the ordinary gelatin; at least such is the result of my observations. And even when the permanent cartilages, those of the larynx, for example, undergo ossification as the result of abnormal action, the ossified portion contains ordinary gelatin in place of chondrin. Bones which are affected with *mollities ossium* contain, by no means, a larger quantity of gelatin, but an extraordinary quantity of fatty matter.

Elastic tissue is yellow, and preserves its property of elasticity for any length of time in alcohol, and it is not deprived of it even by several days' boiling. It yields very little gelatin, and that not until after several days' boiling. The gelatin has peculiar characters; it cannot, therefore, be derived from the cellular membrane which is inclosed in the elastic tissue. It bears a great resemblance to "chondrin," but yet is not identical with it. The solution of the gelatin of elastic tissue is rendered very turbid by acetate of lead and acetic acid, and is precipitated by common alum and by sulphate of alumen; but the sulphate of the peroxide of iron renders it opaline merely, without throwing down any precipitate.

CHAPTER II.

REGENERATION OF TISSUES.

REGENERATION of the different tissues is observed under two forms; in one unaccompanied by inflammatory action, in the other combined with inflammation.

Inflammation, however, must in no case be regarded as the sole cause of regeneration. In man and the Mammalia the two processes often go on simultaneously, and regeneration is frequently excited by inflammation. But still they are essentially different actions; the one is the manifestation of the *vis medicatrix naturæ;* the other an abnormal result of some lesion, and, according to circumstances, it may have an injurious as well as a beneficial tendency. That the regenerative process is independent of inflammation is very evident in reptiles; for in snakes large wounds with loss of substance are healed without any suppurative action; the surface of the wound becomes covered with a crust, under which new substance is formed. This I have myself observed, and the same thing is said to occur frequently in birds. In salamanders and in the lower animals, whole limbs, as we have seen, are reproduced without any attending suppuration, and no one can suppose that inflammation is in these cases essential to the reproduction. In the human subject and in Mammalia, however, inflammatory action and the regenerative process run on together, at least, in open wounds, and the inflammation continues until the part is healed. It is this circumstance which has induced the false conclusion that inflammation consists in the exaltation of a vital process. Even in the higher animals, however, there are some instances of regeneration taking place without its being attended with a trace of inflammatory action, such are the reproduction of the antlers of stags, of hairs, nails, &c.

1. *Regeneration unaccompanied by inflammation.*

a. Organised tissues which, having lost their organisation, are reproduced.—Of these we have examples in the shell of the Crustacea, the antlers of the deer, and the organised bulbs of feathers and spines.

The shell of the crab is renewed every year when the development of the internal organs renders the size of the old shell inadequate. The shell becomes cleft, and is thrown off in August, disclosing a new one already formed beneath it; which, however, is at first soft and endued with sensibility, and even contains vessels, although it soon becomes hardened by the deposition in it of carbonate of lime.* At the time of the change of the shell, chalky concretions—*lapides cancrorum*—are formed on each side of the stomach, and disappear as soon as the new shell is hardened. The stomach of the crab is said to renew its epithelium.

The *antlers of the deer*, and of similar animals, have more analogy with the organised matrix of the horns of ruminating animals than with the horns themselves. The base of the antler rests on the tubercle of the frontal bone, a bony jagged enlargement marking their point of junction. The males throw off the antler, not at the rutting season, (autumn,) but in the spring, and new antlers are then developed. The separation of the old antler is effected by a kind of softening of the organised bony substance of the tubercle of the frontal bone, at the point of its junction with the antler; and the rough surface of the tubercle that is left is soon covered again by skin. The new antler now begins to rise from the frontal process, covered by skin and periosteum; it is at first soft and cartilaginous, and traversed by innumerable vessels. While the cartilaginous mass becomes ossified,—presenting a repetition of the process which takes place in the fœtus and young animal,—the periosteum and cutaneous covering of the antler lose their vitality and drop off; after castration young stags acquire no antlers, and those of old stags are not changed.†

In the same way the organised *bulbs of the hair and spines* in Mammalia, *and of feathers* in birds, have their alternate periods of wasting and turgescence; and hence the casting of the coat of Mammalia, and the moulting of birds, during which the hairs and feathers fall off and new ones are produced. The reproduction of hairs and feathers, however, so far differs from that of antlers, that in the hair it is merely the matrix, which corresponds to the organised antlers, while the shrunken and dry remains of the pulp in the quill may be compared to the hardened antlers which have lost their vitality. The horny substance of the hairs and feathers is secreted by the matrix, and the only part of the antler analogous to it is the cuticle. The reproduction of these parts must, therefore, be considered apart from that of the antlers.

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* Cuvier, Anat. Comparée.

† Cuvier, Anat. Comparée. Berthold, Beiträge zur Anat. Zool. und Physiol.

b. Unorganised textures which are reproduced by the regeneration of their matrix; such are the horny structures, the teeth, and the crystalline lens.

1. *The horny structures.*—The nails, it is well known, are reproduced if their matrix is not destroyed; but the commencing formation of a nail has been observed, even on the middle phalanx of an amputated finger.*

The shedding of the coats of mammiferous animals has been investigated by Heusinger.† He plucked out a whisker hair of a dog, and found, five days afterwards, that a new hair, more than two millimeters in length, had been formed. During the casting of the coat the bulbs of the old hair became pale, and by the side of each a small black globular body is formed, which is developed into the new hair. This is a very interesting fact: the matrix of the new hair is not the old pulp, but seems to be a new sprout from the productive base of the follicle. The spines (of the hedgehog, &c.) are said to be reproduced in the same mode. During moulting, the cuticle on the bill of birds and other parts is cast off in the form of plates or of branny particles. The bulb of the new feather is already formed before the old feather falls out.‡

Several writers§ assert, as the result of experiment, that hairs plucked from their follicles, and inserted into punctures of the skin, will take root and grow. This statement appears to me, however, to require further confirmation. The interior of the bulb of the hair being organised, a union of it with other parts of the skin besides the fundus of the hair follicle, may certainly be supposed to be possible; but how easily may the experimenter be deceived in this observation!

2. *The teeth.*—The crown of the tooth being unorganised, and consequently incapable of growth, so as to correspond with the

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* Blumenbach, Instit. Physiol. p. 511. Dr. Elliotson's Physiology, p. 249.

† Meckel's Archiv. 538.

‡ See A. Meckel, Reil's Archiv. 12. Eble, loc. cit. Burdach, Physiol. Bd. iii. 524.

§ Dzondi, Beiträge zur Vervolkom der Heilkunde. Halle, 1816. Dieffenbach, De regenerat. et transplant. Herbip. 1822. Wiesemann, De coalitu partium a reliquo corpore prorsus disjunct. Lips. 1824.

increased size of the jaw-bones, the formation of new teeth becomes necessary. The permanent teeth begin to appear about the sixth or seventh year, but their crowns are formed at a very early period. Of the twenty temporary or milk-teeth, eight only are molares; the permanent teeth are thirty-two in number, and of these twenty are molares, or twelve true molares, and eight bicuspides.

The dental substance of the first great molaris of the second set begins to be deposited towards the end of pregnancy. The sockets of the new teeth are gradually separated from those of the old, but the two cavities always communicate by a considerable opening through which the common portion of the external layers of the sacs passes. The change of the teeth commences about the sixth or seventh year. The first great molaris is the first of the second set which appears, then follow the incisors and canine teeth, the penultimate molaris not till the thirteenth or fourteenth year, and the last molar between the sixteenth and twentieth year. The roots of the milk-teeth are absorbed before they fall out.

It has been frequently asserted that if the teeth of an animal, after being drawn, are re-inserted into their sockets, they will again take firm root. This appears to me very questionable. If a real organic union takes place in these experiments, it must be by the lacerated vessels of the pulp of the tooth uniting again with the vessels at the bottom of the socket. It is an interesting point which ought to be more accurately determined. A sure way of deciding the question would be, to feed animals, in which the teeth had been recently transplanted, with madder. If any vascular connection had been formed, the innermost layer of the tooth towards the pulp would be coloured red. The teeth not being organised, fissures in them, of course, cannot be closed by the reproduction of new dental substance; they can, at most, be filled with *crusta petrosa*, or tartar from the salts of the saliva. In serpents new poison-fangs are being constantly reproduced. The new teeth of the crocodile press forwards into the conical cavities of the old teeth, the posterior wall of which becomes absorbed.

3. *The crystalline lens.*—It would appear that, in certain cases where the lens has been removed, it is reproduced by the capsule—its matrix. Leroy d'Etiole has observed this.[*] In the first case, thirteen days had elapsed since the extraction of the lens when the eye was examined; in the second case, thirty-three days; in the third, thirty-nine days; in the fourth, thirty-one days; in the fifth, forty-six days; and in the sixth, one hundred and sixty-five days. The experiments were made on rabbits, cats, and dogs. The contents of the capsule were either a crumbly mass, as in the second case; or a small lenticular body, as in most of the other cases; but in the sixth case a full-sized lens was found.[†]

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[*] Magendie's Journ. de Physiol. 1827, 30.

[†] See Mayer, Graefe in Walther's Journ. xvii. 1. Vrolik, ibid. xviii. 4. W. Soemmering, Boebachtungen über die organ. Veränderungen im Auge, nach Staaroperationen. Frankfurt, 1828.

2. *Regeneration accompanied by inflammation.*

Almost all cases of the regeneration of parts of the human body which retain their organisation, are of this kind, if we except the bulbs of the hair and teeth, which are reproduced, and even occur as morbid products in the ovaries and other parts. In the latter case the hairs and teeth are formed in the same way as in their natural situation: the teeth have their covering of enamel, and are formed in follicles.*

a. Regeneration which is accompanied by inflammation attended with exudation of lymph.

If the part, the subject of inflammation, has a free surface, whether there be a wound or not, an exudation of a coagulable fluid,—the liquor sanguinis,—takes place. If it has no free surface, the coagulable matter accumulates in the capillaries and in the texture of the part, and produces thickening and hardening. The matter effused in wounds, and on free surfaces of inflamed parts, is at first fluid; its first appearance on the surface of inflamed membranes being in the form of drops: it is then transparent, but it gradually becomes milky and consistent. It consists of the fibrin which was in a state of solution in the blood. While the exuded matter is still in the fluid state, an impulse towards organisation seems to arise in it, by virtue of a vital property of the fibrin; and by the affinity and reciprocal action of the effused matter with the inflamed surface, organisation ensues. New vessels are formed in the exuded matter. The different modes in which their formation has been described or supposed to take place, and the recent observations of Schwann, have been detailed. One of the earliest steps in the organisation of false membranes is the formation of cells which become elongated and transformed into fibres of cellular tissue.

The organisation of the pseudo-membranes produced by exudation is not universal; those effused on mucous membranes,—for example, in croup,—generally do not, those on serous membranes usually do become organised. The organisation of effused lymph in very many cases cannot be doubted by any one who has seen the beautifully injected preparations in Schroeder van der Kolk's museum at Utrecht, in which the arteries and veins of false membranes, on different parts of the liver and intestines, and of those between the pleura costalis and pulmonalis, are seen injected with different-coloured matters. Lymphatics, too, are formed in the new membranes, as is proved by several of Schroeder's preparations; in which, by the sides of arteries and veins, I saw lymphatics filled with mercury.

The formation of new vessels between the portions of an arterial trunk above and below a ligature, or at the point where it has been divided, is remarkable. It has been observed, and very similarly described by Maunois, Parry, and Mayer. The fact cannot be doubted, particularly since Ebel's repeated experiments and excellent drawings were published.* The new communication is effected by means of several vessels passing, sometimes in a serpentine course, between the two portions of the divided vessel—for instance, of the common carotid. In explaining this phenomenon, the fact has been overlooked, that in other animals than man the common carotid gives off several very small twigs to the muscles of the neck; so that the vessels supposed to be newly formed are probably merely enlarged capillaries.

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* Meckel's Archiv. i. 519.

All organised parts will reunite, when divided, if the surfaces are brought in contact while they are in the state of adhesive inflammation; the divided ends of nerves will unite with nerves, or even with muscle, periosteum, or aponeuroses: and parts even, which have been quite separated from the body, will unite when accurately applied to the surface of fresh wounds, whether of parts of similar or of different structure; but the inflammation in those parts must not exceed the stage of the effusion of lymph. This reunion of organised parts which have been completely separated from the body is certainly extremely rare, but its occurrence cannot be doubted. Buenger's remarkable case of the formation of a new nose from a piece of skin taken from the thigh is an instance of it. All the cases, however, supposed to be instances of this phenomenon, are not equally satisfactory. We can scarcely believe that in Hunter's experiment of the transplanting of a tooth of a dog into the comb of a cock, a real vascular union took place. In another experiment Hunter transplanted a gland taken from the abdomen of a cock to a similar situation of a hen; he also transplanted the spur of a cock; in both cases the removed part is said to have united in its new situation. Abernethy† has described these and other cases; Baronio has made similar experiments.‡ Merrem, and my illustrious teacher V. Walther, assert that the portion of the bone removed by the trephine will reunite.

The reunion of portions of skin only partly separated from the body with other parts, is known to be effected very readily,—for instance, in the case of the formation of a new nose from the skin of the forehead, and in other similar surgical operations. When the skin has united in its new situation, the narrow portion by which it was left connected with the body may be divided. The union of two parts in which inflammation has been excited, is a very general phenomenon in organised bodies, and is taken advantage of in surgery for the removal of solutions of continuity, and as a means of putting a stop to certain secretions. By this process the fœtus may become united with the membranes of the ovum, or two fœtuses may become united together. A very remarkable law prevails in the union of embryos. Almost without exception, it is the corresponding parts of the two embryos that become not simply attached to each other, but as it were fused together; the symmetrical parts of the one embryo, indeed, separate from each other at the point of inflamed in consequence of the injury received at the time of the fracture.

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* Ebel, De Naturâ medicatrice, sicubi Arteriæ vulneratæ et ligatæ fuerint. Giessin, 1826.

† Physiological Lectures, 253. ‡ Froriep's Not. iv. 225.

The only way in which the periosteum aids in the formation of the true callus, is by furnishing to the bone beneath it the vessels which are necessary to the formative and nutritive processes, of which it is the seat. But the formation of special tissues requires, as we have already remarked, some other conditions besides the presence of vessels supplying new nutritive matter.[*]

The circumstance of ossification commencing in the callus close to the surface of the bone, and its extension from this point, show that the presence of bone is here necessary for the production of new osseous substance.[†]

The *serous membranes* are of all textures the most prone to the effusions of the liquor sanguinis of the blood: the reason of this is, perhaps, that they possess the least proper assimilating tissue. Adhesions are, therefore, most frequent in serous sacs. Whether new synovial membranes are formed in the new articular cavities developed around the heads of bone which have remained long dislocated, is at present uncertain, although Meckel, perhaps too positively, asserts such to be the case. The synovia of a new joint may be derived merely from the remains of the old synovial membrane still adhering to the bone.

The cicatrix of a wound of the *skin* which is healed in that stage of inflammation which is accompanied by the effusion of lymph, is more dense than the skin itself; it is sensible, is at first redder than the surrounding skin, at a later period paler; the epidermis covering it is more delicate. Large scars generally result from the healing of those wounds in which a portion of the skin has been lost by the suppurative process. In this case the cicatrix has no hairs; is in negroes, for the most part, colourless at first, but frequently assumes after a time the natural black colour of the surrounding skin.

Solutions of continuity in *mucous membranes* have little tendency to unite; hence in part the difficulties attending the operation for cleft palate and that for wounds of the intestines. In cases of division of the excretory duct of glands, where the divided ends have been kept in contact, regeneration of the duct sometimes takes place and the passage is restored. This fact was first observed by Müller[‡] in three cases of division of the duct of Wharton, and in one of division of the pancreatic duct, in two cases also of division of the *vas deferens* in the dog and cat. Brodie, Tiedemann, Gmelin, Levret, and Lassaigne have, after tying the ductus choledochus, found the passage restored in some cases. In Tiedemann's experiments[§] the jaundice disappeared, in some instances, at the end of ten or fifteen days. The ligature had either cut through the duct and fallen away before the divided edges had united, or coagulable lymph had been effused around the ligature, completing the canal externally, while the ligature, perhaps, had separated and fallen into the cavity of the duct, and had passed out through it. After the lapse of from thirteen to sixteen days the canal was found completely restored.

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[*] Mr. B. Cooper's experiments (Guy's Hospital Reports, vols. ii. and iii.) afforded results which accord with Miescher's view of the mode of production of callus. The substance formed by the periosteum and soft parts became fibrous, and was ultimately absorbed; while that formed by the bone more nearly resembled true cartilage, and underwent ossification.

[†] The question whether the periosteum is able to form new bone will come under consideration at a future page.

[‡] De Vulner. duct. excret. Tub. 1819.

[§] Die Verdauung nach Versuchung. ii.

Solutions of continuity in *glands* cicatrise, it is true; but the new substance has not the properties of the glandular tissue. The same is the case in the cicatrisation of *muscles*. P. F. Meckel, Richerand, Parry, Huhn, Murray, and Autenrieth, all describe the substance by which divided muscles unite as similar to condensed cellular membrane, and as evincing no contractility on the application of galvanism.[*] Wounds of the pregnant uterus cicatrise very quickly; by the contraction of the organ the wound is soon rendered extremely small. It appears that the external serous covering of the uterus has the principal share in the cicatrisation.[†] A new formation of true muscular substance, as described by Wolff,[‡] is certainly not credible. I have seen in the museum at Heidelberg, the fibrous layers on the pleura and pericardium, of which Wolff speaks, but can only regard them as mere fibrinous exudations. We know no test for muscular fibres but their contractility and their microscopic characters.[§]

The question of the *regeneration of nerves* has been investigated experimentally by Arnemann, Haighton, Prevost, Mayer, Fontana, Michaelis, Swann, Breschet, and Tiedemann; but it is still involved in considerable doubt, in consequence of several observers not having distinguished between the mere reunion of the divided ends of the nerve and the possession of nervous power by the matter forming the cicatrix. To prove the latter to be the case, whether anatomically or physiologically, is extremely difficult. Nerves when divided generally retract somewhat by virtue of the elasticity of their sheath; but the fact of the reunion of the divided ends of nerves when they lie in contact cannot be doubted. The new substance, if it has the properties of nerves, must contain nervous fibres. It appeared to Arnemann[‖] to differ in structure from true nervous substance. Fontana,[¶] on the other hand, states that the new substance which united the divided vagus in his experiments on rabbits was similar to nervous substance; but it is impossible that, so early as twenty-nine days after the division of the nerve, the true nervous fibrils could be generated in the cicatrix; for, on examining the new bond of union even after the interval of seven weeks, I was unable to distinguish any nervous fibrils; the new matter seemed still to consist of dense cellular tissue. Prevost* divided the nervus vagus in a cat and allowed it to reunite; and, on examining the cicatrix after four months, found the nervous fibres continued through it. The assertion of Michaelis,† that when portions of nerve from nine to twelve lines in length had been cut out, the ends were again united at the end of some weeks by nervous fibres, is very improbable. To determine whether the new substance of the cicatrix was really nervous substance, Meyer‡ and Tiedemann applied nitric acid, which dissolves the sheath of the nerves, but not the nervous substance itself. This test, however, is a deceptive one: as far as my experience goes, the minute fibrils of the nerves cannot be recognised by any chemical means of investigation; they must be examined by means of the microscope while in a perfectly fresh state. By this method, which is conclusive, and in fact not very difficult, I examined the cicatrix of the ischiatic nerve of a rabbit which had been divided seven weeks before, but could not satisfy myself with any certainty of the existence of parallel fibres in the cicatrix, which was a hard mass, apparently consisting of dense cellular tissue. Schwann, however, has discovered true nervous fibres in the regenerated nervous substance; in his experiment, performed on a frog, the conducting power of the nerve was also restored.

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[*] See Kleeman, Diss. circa Reprod. Partium. Halle, 1786. Huhn, De Regen. Part. Moll. Gött. 1787. Murray, De Reintegrat. Part. &c. Gött. 1787. Autenrieth et Schnell, Diss. de Nat. Unionis Muscul. Vulnerat, Tüb. 1804.

[†] See Mayer in Gräfe und Walther's Journ. 11. 4.

[‡] De Format. Fibrar. Muscul. in Pericardio atq. in Pleurâ. Heidelb. 1832.

[§] See the remarks of Wutzer in Müller's Archiv. 1834, p. 451.

[‖] Versuche über die Regeneration. Gött. 1797.

[¶] Versuche über das Vipernegift.

Experiments of which the object is to ascertain whether sensation and motion are restored in parts after division of the nerves distributed to them, are of great importance; but, unfortunately, most of those hitherto instituted with this view have been deficient in critical accuracy.

Arnemann, who was opposed to the opinion that the nerves are reproduced, once observed, after a cutaneous nerve of the fore-paw of a dog had been divided, that sensation was recovered. Descot§ observed the same thing in a man who had wounded the ulnar nerve; but his case is not conclusive, for the nerve was not completely divided. I was witness to the extirpation of a tumour of the ulnar nerve from the arm of a young man by Professor Wutzer; the nerve was divided above and below, and 2½ inches of it removed with the tumour. It is clear that the nervous substance could not have been reproduced; and nevertheless, at the end of three or four weeks, sensation gradually returned in the ulnar side of the fourth finger, though not in the fifth finger; the return of sensation being evidently attributable to the connection of the palmar branch of the ulnar nerve, which goes in the fourth finger, with a small branch of the median nerve. At the end of eight months, the fourth finger had completely regained its sensibility on both sides. Gruithuisen has observed in his own person a gradual but imperfect return of sensation after division of the dorsal nerve of the thumb. A case is related by Mr. Earle[*] in which a part of the ulnar nerve had been cut out, and in which, in consequence, the little finger at the end of five years was still useless, and the sensations in it very imperfect. In the great majority of Arnemann's experiments, the lower portion of the nerve was quite insensible one hundred and even one hundred and sixty days after its division.

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* Froriep's Not. 360.

† Uber die Regen. der Nerven. Cassel, 1785.

‡ Reil's Archiv. ii. 449.

§ Dissert. sur les affect. locales des Nerfs.

Among the most remarkable experiments on the reproduction of nerves are those of Haighton, Prevost, and Tiedemann. Haighton[†] divided the nervous vagus on one side of the neck in a dog, and three days afterwards divided that on the opposite side; the dog died, as when both nerves are divided at the same time. In a second dog he divided the second nervus vagus nine days after the first; the dog lived thirteen days. In a third, the nerve of the one side was divided six weeks after that of the other side; the dog remained in a weak state for six months, but lived; at the end of six months the voice had returned, and the tones had become higher. Nineteen months after the nervi vagi were first divided, Haighton again divided both nerves one after the other; the animal died on the second day. Richerand repeated these experiments of Haighton with different results. Breschet and Delpech also deny that the nervous substance is regenerated.[‡] Prevost, on the other hand, has confirmed Haighton's experiments; he repeated them on new-born kittens.

In another series of experiments, the proof of the reproduction of the nerves consists in the restoration of the power of motion in limbs, the nerves of which have been divided. From most experiments of this kind no inference at all can be drawn, unless, as in Tiedemann's case, all the nerves of the limb have been divided. Schwann[§] has made many experiments to determine the result of division of the ischiadic nerve in rabbits, from which, however, no certain conclusion can be deduced. The nerves distributed to the muscles of the thigh come off from the ischiadic plexus and the ischiadic nerve very high up, and are likewise in part derived from the crural and obturator nerves; so that division of the ischiadic nerve in the middle of the thigh, and even higher, paralyses merely the muscles of the leg and foot. Although the animals, therefore, will not be able to step perfectly with the foot in such a case, still they will be able to use the leg from the action of the muscles of the thigh being unimpaired.

Too much importance had been attributed to Nysten's experiments,[‖] which showed that, in persons who had died some days after an apoplectic attack, the muscles still retained their irritability—contracted on the application of galvanism,—although the brain had lost its influence; for, in the experiments which I have made with Dr. Sticker, we found that, although the lower portion of a divided nerve retained its irritability for a certain period, still, if the union of the two portions were prevented, the irritability was afterwards lost; so that when at the end of two months the galvanic stimulus of a single pair of plates was applied to the lower portion of the nerve, it produced no contractions in the muscles to which the nerve was distributed. Even when applied to the muscles themselves, the galvanic stimulus in several cases did not excite contraction. The experiments on rabbits made by me, are, therefore, more in favour of the supposition of reproduction of the nerve than opposed to it. In the third experiment only the irritability in the lower part of the nerve was almost completely lost, (although the nerve was allowed to unite,) and in this case, therefore, it seems that the nerve had cicatrised, but that the nervous communication was not restored. Since it appears from Sticker's experiments that, unless their communication with the brain and spinal cord is maintained, nerves cannot preserve their irritability for any length of time, the mere fact that the lower portion of a divided and reunited nerve is irritable after the lapse of several months, proves that the union of the nerve restores in some degree the nervous communication.

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[*] Med. Chir. Transact. 7.

[†] Mem. Med. Soc. v. iii. Reil's Archiv. ii. 80.

[‡] Lund, Vivisectionen, 218.

[§] On the Treatment of local affections of the Nerves, London, 1820, translated into German by Francke. Leipz. 1824.

[‖] Nysten, loc. cit. p. 369.

Schwann has recently performed an experiment, which clearly proves the fact of the reproduction of nerves in the frog:—He divided the ischiadic nerve in the middle of both thighs; after the operation, the frog at first leaped but rarely, generally moving only by crawling; after a month it leaped more frequently, and at the end of three months this movement was performed almost as well as by any other frog. By the aid of the microscope, however, the now united nerve, at the place of division, was seen to contain nervous fibrils, lying close together and running its whole length, and the transparent aspect seemed to result only from the neurilema being less perfectly reproduced. The fibrils were continuous with those of the two ends of the nerve, and the stretching that was necessary for the microscopic examination fully accounted for the nervous cylinders being, at some points, connected only by very delicate threads. The upper end of the nerve was enlarged, as is the case with the ends of nerves in the stump of an amputated limb; the lower portion did not present the same appearance. The nerve of the other side could not be examined. The fact of the reproduction of the nervous fibres after the removal of a portion of a nerve has been confirmed by Steinrück. (Froriep's Notiz. Dec. 1838.)

Without the reproduction of the nervous substance which has been thus demonstrated by Schwann, the experiments of Haighton, Prevost, and Tiedemann are inexplicable. Tiedemann divided in a dog, the nerves of the fore-foot and leg, namely, the ulnar, radial, median, and external cutaneous nerves, in the axilla, and at the expiration of eight months observed a return of sensation and motion, which was still greater after twenty-one months; and at last the dog regained the complete use of the foot. This experiment is most convincing with reference to regeneration of nerve. The return of some degree of sensation in transplanted flaps of skin, even after the division of the portion by which it was connected to its original situation, as in the case of the flap of skin turned down from the forehead to form a new nose, is also an argument for the reproduction of nervous fibres. If in such cases no reproduction of the minute nervous fibrils at the surface of union took place, such a portion of skin, after the division of the connecting isthmus, ought to be quite insensible. I learn from Professor Dieffenbach, the surgeon the most experienced in operations of this kind, that the sensibility remains always very inconsiderable in these parts, but that its existence to a limited extent cannot be denied.

A circumstance, which very much increases the difficulty of imagining the process that takes place in the regeneration of divided nerves, is, that many nerves contain fasciculi of fibres of different kinds,—motor, sensitive, and sympathetic,—of which the first only, as we shall prove hereafter, have power of exciting muscular contractions. In the process of regeneration, therefore, motor fibres ought to unite with motor fibres, and the sensitive fibres with sensitive, which is difficult to conceive of such minute parts. Schwann's principal object in his experiment detailed above was to ascertain whether the union of motor with sensitive fibres could be proved, by the effect of irritating the roots of the nerves in the spinal marrow; whether, namely, irritation of the sensitive roots of these nerves would excite contractions in the muscles of the parts to which the nerves are distributed. With this view he laid bare the spinal cord in the frog, in which both ischiadic nerves had been divided and had reunited, and divided the posterior roots on both sides; no motion was produced in the legs; but when he divided the anterior motor roots, strong contractions of the muscles of the legs took place. This negative result, however, did not prove that no such union of motor and sensitive fibres existed, for it may be that the sensitive nerves are not endowed with the power of communicating an irritation from the centre to the peripheral parts.

The arguments derived from neuralgic cases in support of the opinion of the production of nerves are the weakest of any. After the division of a nerve the extreme branches of which have been the seat of pain, the painful sensations often return. But this might be explained simply by supposing that the affection of the nerve which caused the pain originally is seated higher than the point where the nerve was divided, or that the cicatrix itself excites pains in the nerve. The circumstance, that these secondary pains are felt in the extreme parts, cannot surprise us; for the nervous trunks contain all the separate fibres, the extreme portions of which are distributed in the course of ramification to the different parts; and, as all local sensations depend on the distinct connection of each of these fibres with the brain, affections of the nervous stump may excite sensations which will seem to be in the extreme parts. This occurs even when the extreme branches of the nerve are entirely gone, as in amputated limbs. In all the persons whom I have examined,—persons who had lost limbs by amputation,—twelve or more years after the operation, I found that sensations seated apparently in the lost parts, never entirely ceased to be felt. When the nerves in the stump are pressed upon for a considerable time, the patients suffer distinctly from the sensation of the arm or leg, the greater part of which has been removed, being "asleep." The belief that these sensations are lost a short time after amputation is an error of medical men, who generally do not watch the patients longer than a few months.

Gruithuisen's observations* on the consequences of the accidental division of the nervus dorsalis radialis pollicis, in his own person, are extremely interesting. The nerve was divided by a large transverse wound, at the posterior part of the second phalanx of the thumb, which reached the bone. The left side of the back of the thumb, including even the part covered by the nail was, in consequence, rendered perfectly void of sensation. During the inflammation of the wound, which followed, this portion of the surface became the seat of an enduring, piercing, and burning pain (evidently dependent on the inflammation affecting the upper portion of the divided nerve,—the sensation in the skin being, as in the case of amputations, only illusory). In the course of a week, when the wound healed, these pains ceased, and the part then became insensible as before. After a time, however, it acquired some sensibility, but of an extremely undefined character. If he closed his eyes, while this part (the extent of which was two inches in length, and three-fourths of an inch in breadth,) was touched, he could not determine at what point of the surface the contact took place, erring in this to the extent of from three to five lines. When he struck the cicatrix, he had the sensation of pricking under the nail. Eight months after these observations were made, the sensation was still quite as imperfect as before. Gruithuisen concludes with the remark, that the sensitive impressions can be transmitted through the cicatrix of a divided nerve; but that they become so dispersed in it, that they cannot be transmitted by distinct nervous fibres to the sensorium, and consequently cannot be referred to a determinate spot.

Reproduction of brain and spinal cord.—There are no facts to prove that the consequences of loss of substance of the brain or of the spinal marrow, are ever completely removed by the reproduction of new substance.

Arnemann, it is true, observed that in dogs, in which from twenty-six to fifty-four grains of the substance of the brain had been lost, the wound was afterwards filled by a new, gelatinous, yellow mass, which was more readily soluble in water than the substance of the brain. But it is not certain that this new substance was really cerebral matter. Destruction of the superficial parts of the brain, when unattended with compression or irritation, is often followed by no extraordinary consequences. Lesions of the spinal marrow are, as is well known, but too incurable. Wounds of the brain are stated, by Flourens, to cicatrise very readily, but without the reproduction of nervous substance which Arnemann supposed to take place.

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* Beiträge zur Physiognosie und Eautognosie.

There is at first tumefaction of the wounded parts, but they afterwards collapse and simply cicatrise. The functions of the brain are frequently restored after such injuries, but when this is the case, it takes place often within a few days after the injury; reproduction of the cerebral substance is certainly not the sole cause of it. It is said, however, that when the wall of one of the ventricles of the brain is removed to a certain extent, it is restored by the shooting in of the margins of the opening.

b. *Regeneration with suppurative inflammation.*

Suppuration, or suppurative inflammation, always ensues when a wound is prevented from healing in the stage of fibrinous exudation or adhesive inflammation. Pus is formed by secretion on the surface or in the interior of the inflamed part, and at the moment of its effusion, according to Brugmann and Autenrieth, it is more fluid and transparent. It appears to be formed at the expense of the organised matter, of which the composition is changed by the inflammatory action. The globules of pus are unequal in size;—for the most part they are larger than the red particles of the blood, with which they have no similarity in form; they are either particles thrown off from the suppurating surface, or, like the particles of other secretions, are formed in the fluid at the moment that it exudes, in a manner similar to that of the formation of globules in a solution of albumen at the commencement of its coagulation.

The pus globules are not flattened like the red particles of the blood, but are spherical, or nearly so. Their size varies somewhat, but in the mean is about $\frac{1}{2500}$ of an inch. They appear under the microscope nearly colourless and transparent, and have a granular surface. Each globule contains a nucleus, which acetic acid causes to become very distinct, rendering the outer part of the globule or cell transparent. After a little time the acetic acid wholly dissolves the outer portion of the globule, and a part of the nucleus also; so that only two or three smaller particles, the nucleoli, are left. Besides these, the proper pus globules, there are a number of other much smaller particles floating in the fluid.* By a chemical analysis Gueterbock found that pus contained in solution, besides albumen, a peculiar matter which he has named "pyine."† This substance resembles casein and chondrin in the character of being precipitated by a small quantity of acetic acid and by alum; but it is distinguished from chondrin by not being redissolved by excess of alum, and from casein by the addition of an excess of acetic acid not causing the solution of the precipitate. Muriatic acid also precipitates pyine; but if added in larger quantity, redissolves it. In the acid solution thus obtained ferrocyanuret of potassium throws down no precipitate. Pyine is also soluble in water, and the precipitate which alcohol produces in its solution, may be again dissolved by means of water. The same matter is also contained in mucus, in which, however, the osmazome and albumen of pus are wanting. Pure mucus, moreover, contains no fatty matter; while in pus this is so abundant, as to cause it to burn like sealing-wax, and the microscope sometimes detects numerous fat globules mixed with the proper pus globules.* Pus, too, is miscible with water, and is soluble in acetic acid, while mucus mixes with difficulty with water, and is coagulated by acetic acid.† These differences, however, are due to the fluid portion only of the two secretions; for mucus contains globules exactly similar to those of pus. The observation of Brugmann and Autenrieth, that pus when first secreted is a clear fluid, is confirmed by Vogel and Valentin. The mode of development of the pus globules in this fluid as described by Vogel,‡ accords exactly with the observations of Schleiden and Schwann relative to the formation of the primary cells of the normal tissues. First, granules appear; two or three of them become aggregated together and form a nucleus, around which a semi-transparent vesicle is gradually developed, and acquires the size and character of the perfect pus globules.§

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* Vogel doubts whether "pyine" is an essential component of pus.

† Pus and the pus globules have been examined microscopically and chemically by several observers within the last four years. The best essays on the subject are those of Gueterbock, De Pure et Granulatione. Berolini, 1837; Vogel, Ueber Eiter, Eiterung und die verwandt. Vorgänge. Erlangen, 1838; and Valentin, Repertorium, 1838, p. 172. An account of the observations of the different observers will be found in Valentin's Repert. 1838, p. 164; and Müller's Archiv. 1838, p. xii. and 1839, p. xvii.

In the healing of wounds by the first intention, or by adhesive inflammation, the edges of the wound are united by means of the organisable matter dissolved in the blood. But when wounds heal by suppurative inflammation, there is no effusion of plastic matter. Pus is not susceptible of organisation. Sir E. Home's ideas respecting the conversion of pus into granulations are quite unphysiological. During suppuration and granulation there is no development of new vessels in matter previously exuded on the surface; but the size of the wound is diminished by the interstitial growth of the already organised particles forming its margins and base. The new matter formed in the cavity of the wound, having a granular surface, has received the name of granulations. These granulations contain reticulated capillaries; but no blood-vessels with free open extremities, for such a form of blood-vessels exists in no part of the body. The pus, therefore, is secreted simply by the exposed surface of the granulations. The encroachment of the organised parietes of the wound on the cavity equally from all sides, from the borders as well as from the base of the wound, diminishes its size both in circumference and depth, till it is reduced to a point or quite closed, when the suppuration ceases spontaneously. It is only when the growth takes place more rapidly at the base of the sore than at the borders, that the granulations rise above the surface; and under these circumstances the suppurating wound cannot be reduced till the proper relation between the borders and base of the sore is restored by cauterisation. In the contrary case, when the bottom of the wound is not regenerated so quickly as the margins, the sore becomes sinuous, and requires to be laid open by division of the borders. When the suppuration is very superficial, the secretion of pus ceases simultaneously with the inflammation, without any reduction of the extent of the wound by this growth of the base and margins being necessary. Pauli* has given a representation of the microscopic appearance of the capillaries in a suppurating wound. The structure of granulations has been recently investigated, microscopically, by several observers;† but most accurately by Henle. The surface of the granulations is in great part formed of globular bodies or cells, which resemble pus globules in every respect, except the circumstance of their nucleus not splitting into several smaller bodies under the action of acetic acid; within the most superficial stratum formed by these bodies, are nucleated cells rendered polyhedral by the pressure they exert on each other; and still deeper in the substances of the granulations, the cells are elongated into spindle-shaped bodies, and present the various forms, indicating their transformation into the fibres of cellular tissue, which afterwards constitute the substance of the cicatrix. From these facts, Henle, and other recent writers on this subject, justly infer that both the pus globules and the new substance of the granulations are formed at the surface of the suppurating wound. The process seems to consist in the development of "primary cells" in the plastic fluid effused, and in the assimilation of a part of these cells into organised substance, and ultimately into cellular tissue, while another part of them is cast off in the form of pus globules. If the fluid effused is not sufficiently copious to form liquid pus, the surface of the wound becomes covered with a crust or scab, in which the nuclei of the pus globules can be seen united by a granular matter. When the organising assimilative power is defective, few primary cells are developed in the effused fluid, and the pus is then thin and ichorous, and the wound generally does not heal. On the contrary, if the assimilation is active, the primary cells are formed in abundance, and in that case the pus is thick and creamy, and granulations grow rapidly.

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* Gueterbock, loc. citat. p. 24; and Valentin's Repert. 1833, p. 172.

† Vogel, loc. citat. p. 107.

‡ Loc. citat. p. 152. Vogel's observations were made on fluid secreted by a blistered surface, and on the pus of open wounds.

§ It has been observed by many writers that pus is found in the veins and even in coagula contained in the heart in cases where suppuration has been going on in other parts of the body, but particularly in cases of phlebitis. Mr. Gulliver has recently announced (Philosophical Magazine, Sept. 1838) that pus may, by the aid of the microscope and other means, be detected in the blood in almost every instance in which there was either extensive suppuration or great inflammatory swelling. The translator has had the opportunity of verifying Mr. Gulliver's observation respecting the presence of globules resembling those of pus in the blood in the cases of two patients, under the care of Dr. Burrows, at St. Bartholomew's Hospital, in whom contamination of the circulating fluid with pus was rendered probable both by the symptoms during life and the morbid appearance found after death. But, admitting that the globules found in the blood in such cases are really pus globules, there is still no proof either that they are absorbed from the original seat of the suppurative action, or that the pus effused in the parts secondarily affected consists either wholly or in part of such globules deposited from the blood. It would be much more probable that, the blood being contaminated by the absorption of a morbid fluid, pus globules are developed in it by the same process as on the surface of ulcers, and that the effusion by the liquid part of the blood gives rise to the formation of fresh pus in the same manner in other parts. Mr. Gulliver's supposition that the blood particles are converted into pus globules is improbable, and is supported by no direct observation, except, perhaps, by that of Weber, relative to the transformation of the oval blood disks into colourless globular bodies in the vessels of the larvæ of Batrachia where the circulation has become temporarily arrested in the part. A doubt, however, is thrown on the nature of the pus-like bodies observed by Mr. Gulliver in the human blood and on their relation to inflammatory and suppurative action, by the fact that similar bodies are found in the blood of healthy persons. This last fact was communicated to the translator some months since by Mr. Kiernan, and has been more recently mentioned to him by Dr. Gueterbock.

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* De Vulner. sanand. Comment. Gött. 1825.

† Gueterbock, loc. citat. H. Wood, De Puris Naturâ atque Formatione. Berol. 1837. Vogel, loc. citat. Valentin, Repertor. 1837, p. 263. Miescher, De inflam. Ossium, p. 181; and Henle, Hufeland's Journal, Bd. lxxxvi. 1838.

In cases where a large extent of skin has been lost, it is replaced partly by growth inwards of the skin forming the margins of the wound, and partly by the condensation of the cellular tissue, as has been observed in a striking degree in cases of destruction of a large part of the scrotum. When great loss of skin occurs in cases of necrosis, in which the surface of the bone, from which the dead portion is thrown off, becomes soft and gives rise to a granulating growth, as we have observed in a case of extensive loss of substance of the integuments of the cranium, with necrosis of a large part of the external lamella of the cranial bones in consequence of a burn, the substance which forms the cicatrix seems to be formed in part by prolongation inwards of the surrounding skin, and partly also by the growth of cellular tissue from the surface of the granulating bone, which also forms for itself a new periosteum.

The process which ensues upon *necrosis* of the bones, is a subject of great physiological interest.

Necrosis, or the death of a bone, is the consequence either of the unfavourable termination of inflammation of the bone in a bad constitution, or of its vascular supply being cut off by the destruction of its periosteum or medullary membrane. Destruction of the periosteum, to a considerable extent, cuts off the supply of blood which the bone received through the medium of the vessels of that membrane, and induces the death of the exterior layers of the bone. When the medullary tissue of a bone is destroyed by inflammation, or artificially after a cylindrical bone has been sawn through in an animal, the supply of blood to the internal layers of the bone is in the same way cut off, and their death is the consequence; but in neither case does the whole thickness of the bone lose its vitality. The process which ensues in the external parts of the bone when the internal layers are destroyed, and in the internal parts when the external layers become necrotic, is very remarkable. The osseous substance becomes inflamed; the consequence of which is the effusion of coagulable lymph, as when the ends of broken bones become inflamed; and this coagulable lymph, as in the case of fractures, becomes organised, and afterwards ossified. If the lesion and consequent necrosis is on the outer surface of a cylindrical bone, the exudation takes place on the inner surface into the cavity of the bone, so that the medullary cavity is diminished in size. The callus thus formed on the inner surface of the bone, strengthens it, supplying the loss of substance which it has sustained by the death of its outer layers. If any long bone is sawn across in a living animal, and its medulla destroyed, so as to produce necrosis of the inner layers of the bone, the exudation takes place on the external surface of the exterior, still living, lamellæ. This is best seen when a hot iron has been thrust up the hollow bone of some animal, or when the cavity of the bone has been plugged with wood.

The enlargement of the bone continues during the whole period of its inflammation. It is very distinct where the living bone is in contact with the exfoliated portion; the surface of the bone here becomes softened and exceedingly vascular. The growth of the bone, thus inflamed and softened, has the principal share in the regeneration of the portion of bone which has perished. The laminæ of bone which are still living, become soft, red, and granulating, at the part where they are in contact with the dead bone, whether this consist of the internal laminæ, as in internal necrosis, or of the external laminæ, as in external necrosis; but in the former case the living shell of bone grows towards the exterior, so as to form a strong cylinder around the dead "sequestrum," the living bone beneath the necrotic layers, growing as well towards the exterior as towards the medullary cavity. In the latter case, where the internal layers of the bone are dead, the living shell of bone grows towards the exterior so as to form a strong cylinder around the dead sequestrum. The increase in size of the inflamed and softened bone, goes on as long as the surface in contact with the dead bone continues to secrete pus.

If the whole thickness of a bone has died, no new bone can be produced, the periosteum having no share in the process; but when merely the external or the internal layer has perished, then the bone is usually reproduced. But even in this case an entire new bone is not formed; the cylindrical sequestrum, in the case of internal necrosis, is only the internal laminæ of the long bone, and the new cylinder around it merely the external laminæ of the bone thickened and swollen.

There has been much contention about the question, whether the new osseous mass which encloses the sequestrum, is reproduced merely by the enlargement of external layers of the bones, or is formed by the periosteum itself. Weidmann* supposes that both cases occur. Troja is led by his later experiments to adopt the first opinion, and Scarpa has recently proved it to be correct. Meding, on the other hand, supports the opinion of the formation of bone by the periosteum. It is in itself inconceivable that a membrane, such as the periosteum, which serves merely to contain the vessels which pass from it into the bones, and to invest the latter, can itself form organised osseous substance. I have already given my reasons for not assenting to this opinion. But it can be clearly shown in mammalia, which are better adapted for this purpose than birds, that the formation of the new tube of bone is effected partly by the effusion of lymph in the adhesive stage of inflammation on the surface of and by the inflamed bone itself, not by the periosteum; but that the greatest part of the osseous mass is formed by the continued growth of the living layers of bone which surround the inner sequestrum, during the whole period of suppuration. I rest this statement upon the excellent observations of my colleague, M. J. Weber, which have been made known by M. Bannerth in his interesting thesis, in which drawings from the preparations are also given. The opinion of Scarpa, that the enlargement of the old bone takes place by "expansion," has been shown by Miescher to be incorrect. The growth of the external laminæ of the bone, which retain their life in internal necrosis, is effected by exudation. The description which I have given of the process of reproduction in bone, is founded partly on the examination of Weber's preparations, and partly on Miescher's observations. In conjunction with Dr. Pockels of Brunswick, also, I have examined the bones of several animals on which he had produced internal necrosis for the purpose of experiment, and the results they afforded were the same. On the subject of the reproduction of bone attending necrosis, consult Troja, Neue Beobacht. und Vers. über die Knochen: übers. von Schönberg. Erlang. 1828. Köhler, Exp. circa Regen. Ossium. Gött. 1786. Kortum, loc. cit. Meding, Diss. de Regen. Ossium, Lips. 1823. Scarpa, über die Expansion der Knochen und den Callus. Wiemar, 1828. Bannerth, Naturæ Conaminum in oss. læs. sanand. Indagatio Anat. Physiol. Bonnæ, 1831. The best account of all previous researches on the reproduction of the tissues will be found in the prize essay of Pauli, De Vulner. sanand. Comment. Gött. 1825. To the above, Dr. Baly adds the following remarks and references:—Many very valuable facts illustrative of the whole subject of the growth and reproduction of bone, will be found in Mr. Stanley's Lectures, delivered at the College of Surgeons in 1837. (See Med. Gazette, vol. xx.) Mr. Stanley is of opinion that new bone may be formed not merely by the old bone and periosteum, but also by all the surrounding soft parts. In the Museum of St. Bartholomew's Hospital are preparations demonstrating the formation of plates of osseous substance on the inner surface of the periosteum, in cases where nearly the entire shaft of a long bone had perished, and others showing the results of the experiments referred to by Mr. Stanley in his lectures, in which a portion of the whole thickness of a long bone having been removed in a living animal, but the periosteum being left, a complete regeneration of the bone took place, while the removal of a similar portion, together with its periosteal covering, was attended with a contrary result. Similar facts, derived from morbid anatomy and experiment have been adduced by Mr. Syme (in the Transact. of the Royal Society of Edinburgh) in proof that the periosteum has the power of forming bone. But to render the arguments founded on the pathological cases here alluded to conclusive, it should be shown that the surface of the dead bone was quite smooth—that portions of it had not separated with the periosteum, which could have served as nuclei, for the growth of the new osseous cylinder; and with reference to the experiments on animals, which, at first sight appear so conclusive, it might be objected that the periosteum may be more prone to the exudation of plastic matter than the muscles and other surrounding tissues, and yet the conversion of this matter into osseous substance be effected by an assimilating action, commencing at the ends of the old bones. Mr. Syme, however, relates an experiment in which he merely separated the periosteum from the bone to a certain extent and inserted a thin plate of metal beneath it, and here the lamina of new bone formed on the exterior of the metal plate, was, he states, quite unconnected with the old bone, except through the medium of the periosteum. Even this experiment does not appear absolutely conclusive; for the separation of the periosteum from the bone being, necessarily, a very difficult task, minute portions of osseous substance may possibly be removed with it in the endeavour to maintain it entire. (For the observations of Heyne, whose opinions accord with those of Mr. Stanley, see Graefe und Walther's Journal, Bd. xxiv.; and the Archives Générales de Médecine, April, 1837.)

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* De Necrosi Ossium.

BOOK II.

OF THE CIRCULATING FLUIDS, OF THEIR MOTION, AND OF THE VASCULAR SYSTEM.

SECTION I.

OF THE BLOOD. ITS GENERAL PROPERTIES.[*]

The quantity of the blood in the body cannot be exactly determined: it is calculated, however, that in adult individuals it varies from eight to thirty pounds. M. Valentin has adopted an ingenious mode of ascertaining the quantity contained in the animal body. Having weighed the animal and determined the proportion of solid matter in a portion of its blood, he injects into its vessels a given quantity of distilled water, which soon becomes mixed with the blood. He then takes away a fresh portion of blood, and ascertains the proportion of solid matter in it. The relation between the amount of solid matter in the blood first taken, and that in the blood diluted with the given quantity of water, enables him to calculate very easily the quantity of the entire blood in the body of the animal.[†] In this way M. Valentin has ascertained the relative quantity of the blood to be in

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[*] On the blood generally, consult Parmentier and Deyeux in Reil's Archiv. b. i. heft. 2, p. 76.—Hewson's Experimental Inquiries, 1772; in German. Vom Blute. Nürnb. 1780.—Prevost and Dumas, Bibliothèque Universelle, tom. xvii. p. 294.—Meckel, Archiv. viii.—Scudamore on the Blood, London, 1824; or über das Blut aus d. Engl. Würzburg, 1826.—Berzelius, Thierchemie, 1831; or the 7th volume of his Traité de Chimie, translated into French by M. Esslinger.—Denis, Rech. Experim. sur le Sang Humain, Paris, 1830.—Thakray, Inquiry into the Nature of the Blood, London, 1819.—Dr. G. Burrows, Croonian Lectures for 1834, in Medical Gazette.

[†] Thus 1190 grains of blood taken from the left jugular vein of a large dog, yielded 24·54 per cent. of solid residue. After the injection of 10,905 grains of water into the blood-vessels, 1139 grains of blood taken from the right external jugular vein, afforded 21·86 per cent., and 1274 grains from the left external jugular 21·89 per cent., of solid residue. The proportion of solid residue in the diluted blood was therefore 21·87 per cent. Now the quantity of water injected (viz. 10,908 grains) multiplied by the proportion of solid residue in the diluted blood (or 21·87 per cent.) and divided by the difference between the residue of the blood thus diluted, and that of the blood before the injection of the water (that is 24.54—21·87), gave 89,323 grains as the quantity of blood which remained in the body after the extraction of the first 1190 grains; and by the addition of this last quantity, the whole amount of blood in the body at the commencement of the experiment was found, namely, 90,513 grains. The weight of the dog was 402,641 grains, the proportion of the blood in its body was therefore, as 1 : 4·44.

Large dogs	as 1 : 4·50	(the mean of four experiments).
A lean debilitated sheep	as 1 : 5·02	
Cats (female)	as 1 : 5·78	(the mean of two experiments).
A large female rabbit	as 1 : 6·20	

In animals of the same species, the relative quantity of blood seemed to be constant, whatever was their size. A bitch, however, seemed to contain less blood than the male dogs. The difference observed in the proportional quantity of the blood in different animals accorded with their size; large dogs contained the most, the rabbit the least blood.

In calculating from the data afforded by these experiments on animals the amount of blood in the human body, M. Valentin deemed it best to take the relative weight of the blood in the body of the dog as the standard, namely, 1 : 4·36 for the male sex, and 1 : 4·93 for the female: and then, adopting M. Quetelet's table of the weight of the human subject at different ages, he found that the mean quantity of the blood in the male adult, at the time when the weight of the body is greatest (namely, at 30 years), should be about 34½ lbs., and in the adult female at 50 years, when the weight of the body in that sex is at its maximum, about 26 lbs.

The blood is the fluid from which are derived the materials for the formation and nutrition of all parts of the animal body. It receives the effete decomposed materials from the different tissues, for the purpose of their excretion by special organs; and it is renovated by the new nutrient matters poured into it by the lymphatic vessels. The nutrient matters consist partly of substances introduced from without, and partly of matters which have already been organised components of the body. Their conversion into blood is effected not so much, probably, by the operation of particular organs as by the general action of all parts of the system upon them; for in the ovum, even before most of the organs exist, and when the first traces only of the central parts of the nervous system are formed, blood is generated within the *area vasculosa* by the germinal membrane, which is the *cicatricula* or germ more fully developed by the attraction and assimilation of the fluids of the ovum.

The blood which is brought to the heart from the lungs by the pulmonary veins, and projected by the left ventricle through the aorta and its branches into all parts of the body, has a *bright* red colour; that which returns through the venous system of the body to the right ventricle, and is thrown by it again into the lungs, has a *dark* red colour. The blood is also red in some invertebrate animals, as some of the Annelida (red-blooded worms). It has a reddish colour in some of the Mollusca, at least in the Planorbis, according to the observation of Treviranus and myself, and in an Entozoon allied to the Planariæ, according to M. Milne Edwards. In many invertebrate animals it is colourless.

If the blood is examined with the microscope either in the minute vessels of a transparent part, or immediately after it has flowed from the body, it is seen to consist of small *red particles* or *globules*, and a clear colourless fluid. This fluid is the *lympha* or *liquor san-*

guinis, and must not be confounded with the serum, which is the thin fluid that separates from the crassamentum during coagulation. The *liquor sanguinis* can be obtained free from the red globules before coagulation takes place, by filtering the blood of the frog or any other animal in which the red globules are so large as not to pass through white filtering paper. The red particles are specifically heavier than the fluid, and consequently can contain no gasiform substance.

The specific gravity of human blood varies from 1·0527 to 1·057. It has a saltish taste, a weak alkaline reaction, and a peculiar odour,—*halitus sanguinis*,—which differs somewhat in different animals, and is strongest in the blood of the male sex.

The blood of all vertebrate animals usually coagulates within the period of from two to ten minutes after its escape from the vessel; the blood of the human subject requires from three to seven minutes for its coagulation, that of the rabbit two minutes only. It becomes first a gelatinous mass; but this slowly contracts, and presses out a dull-yellow fluid,—the *serum*,—which appears first in drops on the surface of the coagulum, and gradually increases in quantity. The red coagulum is called *crassamentum*, *placenta*, *coagulum sanguinis*, or *clot*.

The *serum* has a specific gravity of from 1·027 to 1·029. It has a saltish taste, and in the higher animals a weak alkaline reaction, which is scarcely perceptible in the frog. Hermann was led into the error of supposing the serum to be acid, by observing that blood treated with tincture of litmus, yields a reddish serum, which really arises from the red colouring matter of the globules being soluble in the tincture, just as it is in water. The serum holds in solution several animal matters, of which the chief is *albumen*. This substance requires for its coagulation the action of certain chemical agents, such as acids and alcohol, or a temperature of 158° Fahr.; it does not coagulate spontaneously.

If the red *coagulum* is washed for some time in water, the colouring matter is dissolved, and a white fibrous substance remains which is called *fibrin*. This substance, like the red clot, sinks in water unless it accidentally contains bubbles of air.

In females during pregnancy and in the puerperal state, in acute rheumatism and in inflammation,—indeed in all cases where the blood coagulates more slowly than usual,—the red globules often subside below the surface of the fluid before coagulation takes place, and the consequence is, that afterwards, when the whole mass coagulates, the upper part of the clot is white,—forming the inflammatory crust or buffy coat,—while the lower part is red. When fresh blood is stirred quickly, the red globules are not included in the coagulum; the fibrin coagulates slowly into colourless fibres, which adhere to the rod with which it is stirred, while the rest of the blood remains fluid with the red globules floating in it. Fresh blood, if exposed to a very low temperature, freezes, and may in that state be preserved, so as to be still susceptible of coagulation when it is thawed. Alkalies prevent the coagulation of the blood; even a thousandth part of caustic soda has this effect. Some salts also, as sulphate of soda, nitrate of potash, carbonate of soda, and carbonate of potash, when mixed with the blood out of the body, prevent or retard this phenomenon. Fontana states that the poison of the viper, and that of the ticuna, added in the proportion of one part to twenty parts of blood, have the same effect, while the viper's poison quickly induces the coagulation of the blood when inserted into a wound of the living body. There are certain circumstances, also, in which the blood remains fluid in the vessels, namely, in men and animals killed by lightning or strong electric shocks, in those poisoned by prussic acid, in animals hunted to death, and in men killed by violent blows on the epigastrium; and it is said that in these cases the limbs do not become rigid.* In persons, also, who have died after protracted dyspnœa terminating in asphyxia, the blood is generally found fluid, at least for a much longer period than usual after death.

Except under the circumstances just stated, blood, when removed from the body, always coagulates, whether it is kept at rest or in motion,—whether it is placed in a temperature equal to that of the living body,† *in vacuo,* in close vessels quite filled so as to exclude the air,‡ or in various gases which do not form part of the atmosphere. The sole cause of the coagulation of the blood is, that the proper combination of its elements is maintained so long only as the blood is under the influence of living surfaces, viz. of the vessels. Blood extravasated in the body, also, generally coagulates. Blood which is enclosed in a vessel between two ligatures, or of which the motion in the vessels has been impeded in any way, coagulates, though more slowly than out of the body; it seems necessary, therefore, not only that the blood should be in contact with living surfaces, but also that it should continue in motion so as to be constantly brought into relation with fresh parts of them. Schroeder van der Kolk's§ experiments seem to show that coagulation takes place with extraordinary rapidity after the brain and spinal marrow have been broken down; in a few minutes after the operation, coagula were found in the great vessels. Mayer observed that, after the application of a ligature to the nervus vagus, the blood coagulated in the vessels, and that death was thus produced. Four experiments, however, which were performed under my direction, two on dogs and two on rabbits, did not confirm this observation, although the animals were examined immediately after death, which was the effect of the operation, a ligature of the nervus vagus: in two cases only was a small coagulum of the size of a pea discovered in the left side of the heart, and none in the pulmonary vessels. Hewson, Parmentier, and Deyeux have observed that blood extracted from the vessels, coagulates more rapidly in proportion as the vital powers of the animals decline. Several observers—Gordon, Thomson, and Mayer, for example—declare that they have observed elevation of temperature during coagulation; while Dr. J. Davy* and Schroeder van der Kolk deny this most decidedly.

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* Abernethy, Physiolog. Lectures, p. 246.—Hunter on the Blood, Works by Mr. Palmer, vol. iii. p. 41, Amer. edit.

† According to Sir C. Scudamore, cold retards coagulation, while heat accelerates it.

‡ Dr. B. Babington (Med. Chirurg. Transact. vol. xvi.) has shown that coagulation is *retarded* by exclusion of air, and to such a degree, that the red particles have time to subside. By letting blood flow into a vessel containing oil, he obtained a thick fibrinous covering, while a portion of the same blood received into an empty vessel formed no buffy coat.

§ Comment de Sanguinis Coagulatione. Gröningen, 1820. Diss. sist. Sang. Coagulantis Historiam. Gröning. 1820.

CHAPTER I.

Microscopical, Mechanical and Chemical Examination of the Blood.†

The parts into which the blood first divides are, the *red particles* and the *liquor sanguinis.* This last is found to consist of *serum,* and *fibrin* in solution; and the serum, again, is composed of the coagulable portion, or *albumen,* which is held in solution by an alkali, also *casein, salivin, osmazome* and *water,* with *salts of soda and potash,* viz. *lactate of soda* and *chlorides of potassium and sodium. Fatty matter,* rarely in a free state in the blood, is combined most generally with the fibrin, colouring matter and albumen of this fluid. We proceed now to speak of these several principles, except where,—as in the case of fibrin, in a great measure, and albumen, osmazome and fatty matter entirely,—they have been described under the head of *General Anatomy* in the First Book.

OF THE RED PARTICLES.

There is great want of accordance in the descriptions which writers have hitherto given of the red particles of the blood.‡ I shall state here merely the results of my own observations.§

Mode of examining the red particles.—For the purpose of microscopic examination, the blood must not be diluted with water; for this fluid has the property of immediately changing the red particles from a flattened to a spherical form, and of rendering circular those which were elliptical. The blood should be either diffused very thinly over the surface of the glass, or diluted with some serum or a weak solution of common salt or sugar; these solutions produce no change in the appearance of the red particles. The method I adopt in examining these bodies in the blood of the frog is, to place a small quantity of the serum of the blood of this animal on the glass, and to add to it a small quantity of the fresh blood. It is doubtless attributable to the use of bad instruments, and to the blood having been diluted with water, that the descriptions given of the red particles have been so various.

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* Tentamen experimentale de Sanguine. Edinb. 1814.—Meckel's Archiv. i. 117, ii. 317, iii. 454, 456.

† From original researches. See Poggendorf's Annal. 1832. 8. Berzelius is chiefly followed for the chemical part.

‡ A full account of the observations of different physiologists will be found in E. H. Weber's edition of Hildebrandt's Anatomie, Bd. i. and in Burdach's Physiologie, Bd. iv. The best observers have been Muys, Fontana, Nouvi Osservazioni sopra i globetti rossi del sangue, Lucca, 1766.—Hewson, Experimental Inquiries, pt. iii. Lond. 1777.—Prevost and Dumas, Biblioth. Univers. t. xvii.—Meckel, Archiv. t. iii.—R. Wagner, zur vergleichende Physiologie des Blutes, 1834.

§ The most important facts relative to the form and properties of the red particles of the blood were known to Hewson. A short historical account of the observations of different physiologists on these bodies was given by the translator in the former edition of this work.

The form of the red particles in different animals is very various; but whether elliptical or circular, they are always flattened.

In mammalia, except in the dromedary and alpaco, including the human subject, they are circular disks. I have examined them in the calf, cat, dog, and rabbit, as well as in man; and am convinced that they are flattened in all these animals as well as in birds, reptiles, and fishes. In these and in amphibia, they are elliptical. In some fishes they are more nearly circular, but never perfectly so.* In reptiles, amphibia, and birds, the long and short diameters of the red particles are about in the proportion of two to one.

They may be compared to a piece of money seen edgeways; but, in proportion to their long diameter, they are much thicker than a piece of money. In human blood their thickness is about one-fourth or one-fifth of their transverse diameter.

The flattening is greatest in reptiles, amphibia, and fishes; and of all animals it is most remarkable in the salamander. In birds, also, the red particles are decidedly flattened; but not to so great a degree as in amphibia.

Central spot.—In the centre of each red particle is a spot, which in the circular bodies is circular, in the elliptical also elliptical; on the illuminated side of the particle it appears light, on the opposite side dark. This spot has sometimes—I may say, indeed, has always in the elliptical globules—the appearance of being produced by a central nucleus, especially when the particle is brightly illuminated, and all shadow avoided.

I will presently detail experiments by which I am able to demonstrate the existence of a nucleus, with chemical characters perfectly different from those of the outer vesicle, in each of the red particles of the frog and salamander. And as this nucleus has under the microscope exactly the same appearance in the red particles of birds and fishes as in those of amphibia, it would be expected to exist in those of mammalia also. And although, on account of the minuteness of these bodies in mammalia, it is more difficult to demonstrate the nucleus in them, I have really seen it distinctly with an excellent microscope. Even in the red particles of human blood, I have seen a minute, round, accurately defined nucleus, which had a more yellowish and shining aspect than the transparent part around it. The existence of the nucleus here can also be demonstrated by the action of acetic acid, though much less distinctly than in the case of frog's blood.

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* Rudolphi describes the red particles of fishes to be circular, and I formerly thought they were so in the Clupea alosa; but it was before I was acquainted with the right method of examining them. The error arose probably from inaccurate observation, or from diluting the blood with water. According to Prof. Wagner's observation, also, the blood corpuscules of fishes are in some instances elliptical, in others more nearly circular.

The size of the red particles in human blood is pretty uniform; some few are larger than others, but none have twice the diameter of the majority. In the frog, also, their size is for the most part equal; some, however, without differing in any other respect, are somewhat smaller than the rest, and appear to be in the process of formation. Prevost and Dumas have found the red globules in the embryo to be larger than those of the adult animal. In the embryo of the rabbit their dimensions are very unequal; the greater number are of the same size as in the adult, and a few are more than twice that size. In the tadpole the same bodies appear to be somewhat smaller than in the frog, and are much paler.

The red particles of amphibia are the largest that I am acquainted with; in birds, reptiles, and fishes, they are of less size; in mammalia smallest, and among mammalia those of the goat are the most minute, as Prevost and Dumas correctly observed. In the calf they are rather smaller than in man. The red particles of frog's blood being taken as a standard of comparison, and observed under the microscope side by side with those of other animals, it is found that those of birds are about one-half the size of those of the frog; that the red particles of the salamander are not quite one-third larger than those of the frog, and are rather more elongated: the blood particles of the lizard, compared with the same bodies from the frog, are found to be about two-thirds the size, while the circular particles of human blood measure only one-fourth the long diameter of the elliptical particles of frog's blood. The red particles in the Proteus anguinus are, according to R. Wagner, larger than in any other known animal; they are twice as large as those of the blood of the frog. The red particles in man I have found to measure from 0.00023 to 0.00035 of a French inch, $\frac{1}{4013}$ to $\frac{1}{2837}$ of an English inch in diameter.

Lymph globules in the blood.—In the blood of the frog as obtained from the heart of the animal, I have found other smaller bodies, much less numerous than the red particles, about one-fourth their size, and perfectly spherical. They are colourless and have a granulated surface. In the blood of the elephant Prof. C. H. Schultz* found corpuscules of several different forms; namely, globular colourless bodies containing each a large nucleus, other bodies slightly coloured, with one side flattened and the other rounded, and, lastly, intermediate forms between these and the completely flattened and red blood particles. The colourless globules in the blood of the frog agree in every respect with the scanty globules of the lymph of the same animal, which will be described in the chapter on the lymph, and are evidently identical with them, being received into the blood with the lymph and chyle. The relation in which these lymph globules of the blood stand to the red particles will be considered hereafter.

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* Müller's Archiv. 1839, p. 252.

It is generally believed that the conversion of the chyle into blood is effected very quickly. Such may certainly be the case; but the difficulty of distinguishing the chylous globules in the blood, is sufficiently explained by their being diffused among the more numerous red particles. During the ordinary coagulation of the blood of man and mammalia generally, the chylous globules are included in the crassamentum with the much more numerous red particles, and the serum is left transparent; but if coagulation is retarded by the addition of a minute proportion of carbonate of potash, the red particles subside, while the chylous globules being lighter, are suspended in the upper part of the fluid, rendering it milky.

Different action of serum and water on the coloured envelope.—Sir Everard Home* speaks of the red particles undergoing rapid decomposition; this is quite incorrect. The blood of a mammiferous animal from which the fibrin has been removed by brisk stirring, retains all the appearance of fresh blood, and the red particles remain suspended in it, with no change of their form or size discoverable by the best microscope after the lapse of several hours, or even on the following day. But if water is added to such a mixture of the red particles and serum of the blood of a mammiferous animal, a part of the colouring matter is quickly dissolved, and a large portion of the red particles sink to the bottom of the vessel.

The solubility of the colouring matter in water enables us to demonstrate the existence of a nucleus in each of the red particles. For this purpose a watch-glass should be filled with a mixture of the blood and water, and after waiting a short time for the particles to subside, the whole should be immersed in a large glass vessel partly filled with water, taking care not to disturb the sediment in the watch-glass. After standing for eighteen or twenty-four hours, the red deposit will have become white; and, if some of it be examined with a microscope, the elliptical red particles will no longer be seen, but in their place a great number of small bodies, not more than a fourth the size of the original red particles, and for the most part roundish in form, a few only being oval. If the sediment is examined at intervals during the period mentioned, it will be quite apparent that, in proportion as the water becomes tinged with the colouring matter, the elliptical particles lose their red envelope and become smaller and smaller until the colourless nuclei merely remain. These nuclei are not further soluble in water, but form at length a mucous matter at the bottom of the glass, still consisting of the same granules. The nuclei of the red particles cannot be demonstrated in this manner in human blood on account of their minuteness; but from analogy it is probable that, when human blood is treated in the same way, the nuclei of its red particles also remain undissolved, but are suspended in the water. When the blood of mammalia coagulates, the red particles are included in the clot; and when the red colouring matter is extracted by washing in water, the nuclei may still remain in the fibrinous mass, or they may be separated from it, becoming suspended in the water, but they are not dissolved. Water, as Berzelius remarks, dissolves the colouring matter of the blood corpuscules in all proportions. Prevost and Dumas had denied this; but the experiment just described, particularly when performed with frog's blood, proves beyond doubt that the colouring matter is really dissolved, and not merely suspended in minute particles in the water.

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* Philosophical Transactions, 1818.

Berzelius seems to attribute the insolubility of the colouring matter in serum, to the albumen which this fluid contains. But I cannot think that this is the sole cause, and believe this property of the serum to be chiefly owing to the salts which enter into its composition: for when I added to a small quantity of the frog's blood under the microscope a solution of yolk of egg, the change in the red particles from the flattened to the spherical form took place as rapidly as when I added pure water; but when, in place of the solution of yolk of egg, I added a watery solution of any salt which produces no chemical change in the blood, such as carbonate of potash, or common salt, the form and size of the red particles were not in the slightest degree altered.

Effects of different re-agents on the red particles.—The nature of the red particles of the blood is much elucidated by the changes produced in them by the action of various fluids. To watch these changes a good compound microscope is required, and the blood of the frog or salamander must be employed. A drop of the frog's blood freed from the fibrin, and a drop of any fluid of which we desire to try the effect, should be placed side by side upon a plate of glass, and the two drops made to unite, the effects produced at the moment that they become mixed being watched by means of the microscope; or the red particles may be first examined separately, and again after the re-agent has been added. This is the method I have constantly adopted in the following experiments.

Water.—The instantaneous effect of water on the red particles is very remarkable. Those of human blood become indistinct; the further changes that they suffer cannot be distinguished with accuracy, on account of their minute size: I think, however, that they are rendered globular: for, while they were floating about under the microscope, I could perceive none with a sharp border. But in the blood of the frog every change is distinctly seen; the elliptical bodies immediately become globular, no longer presenting a sharp edge to the eye as they roll over in the fluid. Whether they are enlarged at the same time, I cannot determine; their diameter is now intermediate between the long and short diameter of the ellipsis which they before presented. Many appear unequal in size, are uneven on the surface, and of irregular form; the majority are globular, but not accurately so. In several the nucleus is displaced,—is no longer at the centre, but at the side; in a few it is wholly wanting; in these it seems as if the violent change produced in them by the water had caused the expulsion of the nucleus; for, besides these globules which have lost their nuclei, a few nuclei without envelopes can also be seen strewed over the field of the microscope. These free nuclei are distinguished from the smaller globular or chylous particles of the frog's blood, already described, by their elliptical form. More water being added, the red particles gradually diminish in size, dissolving away, till at length nothing but the insoluble nuclei remain. Water in which carbonate of potash, common salt, sal ammoniac, or sugar has been dissolved, produces no change in the size and form of the globules, unless the solution of carbonate of potash is saturated, when it seems to produce a slight and gradual diminution of their size.

Acetic acid.—If, instead of water, dilute or concentrated acetic acid is used, the elliptical particles immediately become irregular in form, and some are rendered globular. The red colouring matter is in a few minutes almost entirely dissolved, leaving small bodies not more than one-third or one-fourth the diameter of the original red particles. These are not globules contracted by the action of the acid, but nuclei deprived of the red colouring matter. By means of acetic acid, the extremely minute nuclei of the red particles of the blood of mammalia can be rendered visible; but the most careful manipulation, and a very good microscope, are required for the observation.

If the blood of the frog freed from fibrin is mixed in some quantity with acetic acid, the same change in the globules takes place; but we also observe that the nuclei subside in the form of a light brown powder, which, after the lapse of several days, remains undissolved, and which is found even at a later period, if examined by the microscope, to consist of the unaltered nuclei of the red particles. Fibrin and albumen are not rendered brown by the action of acetic acid; on the contrary, it renders them transparent, and by degrees in part dissolves them. The brown colour of the deposit, therefore, seems to depend on some of the colouring matter which still adheres to the nuclei, and is perhaps chemically changed; for the nuclei obtained by subjecting the red particles to the action of a large quantity of water are white, and remain so when acetic acid is poured over them. The acid used in these experiments was ascertained to be pure, and was somewhat more concentrated than the acetic acid of the Prussian pharmacopœia.

Muriatic acid does not dissolve all the colouring envelope; it diminishes the size of the red particles very slightly. *Chlorine* destroys the colour; the frog's blood becomes first brown, afterwards nearly white, like milk, the albumen coagulating into globular granules. If this white matter is examined by the aid of a microscope, the form of the elliptical particles of the blood can still be distinguished in it, but they are somewhat smaller.

The form of the red particles is not affected by *oxygen* or *carbonic acid.*

Liquor potassæ dissolves the red particles very quickly,—the nuclei as well as the colouring envelope,—without previously changing their form. Their solution is effected still more rapidly by *liquor ammoniæ*, and is also complete; but at the moment of mixture the red particles become globular. *Alcohol* causes merely slight contraction of them; and the globules of albumen, produced by the coagulation of the serum, cloud the field of vision and render the red particles indistinct. *Strychnia* and *morphia* produce no change in them.

The size and form of the red particles are the same in *arterial* and *venous* blood. This is contrary to the statement of the otherwise accurate Kaltenbrunner, who describes them as increasing somewhat in size, and losing their defined border, which is dissolved away, as it were, in their passage through the capillaries.

The blood of invertebrate animals has floating in it bodies analogous to the red particles of the blood of vertebrata, but proportionally much less numerous. The form as well as the size of these bodies is very various. The action of acetic acid renders the presence of a granular nucleus in their interior very evident, though, without the aid of this re-agent, the nucleus is sometimes visible. It is most probable that the blood particles of all animals have nuclei.

Chemical Analysis of the Red Particles.

The nuclei.—No complete chemical analysis of the nuclei of the red particles has hitherto been made, on account of the difficulty of obtaining these bodies in sufficient quantity. The red particles being large in frog's blood, the nuclei can be easily obtained free from their envelope by the method already described. They are insoluble in water, and in acetic acid they remain several days without undergoing any change; while they are soluble in a solution of alkali—of soda and potash, as well as of ammonia. In these characters they resembled coagulated fibrin and albumen, but the latter substances are more soluble in acetic acid.

The chemical properties of the *envelope* of the blood particles also are but little known. It is impregnated with the red colouring matter, which is readily, and in all proportions, soluble in water. Acetic acid does not completely dissolve the envelope, but leaves a delicate pellicle around the nuclei. (See page 148.)

The colouring matter of the red particles, the fibrin dissolved in the blood, and the serum from which the fibrin has separated, are susceptible of a more complete analysis.

The colouring matter, hæmatin, cruorin.—Berzelius has analysed cruorin in three states:—

1st. As it exists in the red particles; 2d. dissolved in water; 3d. in the coagulated state, in which it is insoluble in water.

1. The colouring matter in its natural state has a great affinity for

oxygen, uniting with it, and becoming of a brighter colour whenever it comes into contact with it or with atmospheric air. Carbonic acid is at the same time developed; this was the result of the experiments of Berthold, and of those of Christison and myself. If a stream of oxygen is passed through blood from which the fibrin has been removed, the fluid becomes throughout of a bright red colour. The same change is effected on the surface of blood thus prepared, as well as of freshly drawn blood, by mere exposure to air. By long contact with oxygen the colouring matter becomes black, (owing, perhaps, to the carbonic acid formed having united with it,) and the bright red colour cannot then be restored. Carbonic acid, sulphurous acid, and the acids generally, change the colour of the blood to a dark brown. Blood from which the fibrin has been removed, absorbs nitrous oxide in large quantity, and becomes of a purple red colour; but its natural colour is restored by transmitting through it a stream of atmospheric air. Carburetted hydrogen also is said to communicate a brighter colour to dark blood. Several salts—for example, common salt, nitre, and sulphate of soda—have the same effect.* Schroeder van der Kolk observed that bright red spots were produced on the surface of venous blood by the electric spark.

The colouring matter is dissolved by water in all proportions. It is obtained in the state of solution by washing the crassamentum; but as we cannot avoid removing the nuclei at the same time, these bodies suspended in the fluid necessarily enter into its analysis.

2. *The solution of cruorin* is reddened less strongly than blood by exposure to air. By evaporating it at a temperature of 122° Fahr. a blackish mass is obtained which can be rubbed to a dark red powder, and is then again soluble in water. At 158° Fahr. the colouring matter in the watery solution coagulates, and is then insoluble. Alcohol and the mineral acids also coagulate it; and the addition of an alkali to its solution in acetic acid, or of an acid to its solution in an alkali, likewise precipitates it in a coagulated state. Of the precipitates thrown down by the salts of earth and metallic oxides, some are brown; others are black, and others red.†

3. *In the coagulated state* produced by a heat of 158° Fahr., the colouring matter is red and granular; when dried by heat, it becomes black. The long action of boiling water changes the red colouring matter, just as it does fibrin. Acids also form with coagulated cruorin, as with fibrin, neutral combinations, soluble in pure water; those formed with cruorin being of a dark brown colour. The coagulated cruorin is soluble in alkalies also. It is precipitated from its solutions in alkalies and acids by tannin. Tiedemann and Gmelin have discovered that it is slowly soluble in alcohol, giving this fluid a dark red colour. It may, therefore, be separated from the albumen which it contains, by means of alcohol, in which the albumen is insoluble. Lecanu, on this account, regarded the substance forming the pellicle of the red particles,—the hæmatosine,—as a compound

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* Berzelius, loc. cit. p. 48. See also Dr. Burrows's Croonian Lectures. Med. Gazette, 1834.

† Berzelius, loc. cit. pp. 50, 51.

of the true colouring matter which he calls globulin, and albumen. There is, however, no reason for this supposition; for the albumen may be derived from some serum, or from the nuclei of the red particles, separated with the colouring matter from the clot during its ablution.[*] Michaelis gives the following as the result of his analysis of this substance:—

	In Arterial Blood.	In Venous Blood.
Nitrogen,	17·253	17·392
Carbon,	51·382	53·231
Hydrogen,	8·354	7·711
Oxygen,	23·011	21·666
	100·	100·

From this it appears, that the elementary composition of the colouring matter agrees with that of fibrin. The ashes, however, left by the former substance, when calcined, are in larger quantity than that obtained from fibrin, and contain a considerable proportion of iron. The assertion of Brande and Vauquelin, that the colouring matter does not contain a larger proportion of iron than the serum and other animal substances, has been proved by Berzelius and Engelhardt to be incorrect. Oehlenschläger[†] also discovered iron in the blood of puppies which had not yet sucked. Iron is therefore not an accidental ingredient derived from the food. The ashes of the colouring matter are always alkaline, and of a red brown colour; and, according to Berzelius, in human as well as in bullock's blood amount to 1¼ or 1⅓ per cent. of the weight of the dried colouring matter. In the colouring matter of calf's blood it amounts, according to Michaelis, to 2·2 per cent. Berzelius, in the analysis of 1·3 part of ashes, obtained from 100 parts of dried colouring matter, found

Carb. soda, with traces of phos. soda.	0·3
Phosphate of lime,	0·1
Pure lime,	0·2
Subphosphate of iron,	0·1
Oxide of iron,	0·5
Carbonic acid, and loss,	0·1
	1·3

In another experiment Berzelius obtained from 400 grains of dried colouring matter, five grains of ashes, which were composed of

Oxide of iron,	50·0
Subphosphate of iron,	7·5
Phosphate of lime, with a small quantity of phosp. magnes.	6·0
Pure lime,	20·0
Carbonic acid, and loss,	16·5
	100·0

The average result of Berzelius's experiments is, that the colouring matter contains rather more than one-half per cent. of its weight of metallic iron. According to Lecanu,[‡] the ashes of the red pure colouring matter obtained by his new process from human blood, contain 10 per cent. of oxide of iron. Few persons have hitherto found manganese in the blood. In two grammes[*] of blood-ashes, Wurzer[†] found 0·108 of oxide of iron, and 0·034 of oxide of manganese.

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[*] Lecanu, in Poggendorf's Annal. 1832, iv. 550.

[†] Kastner, Archiv. 1831, Sept. Oct. p. 317.

[‡] Etudes Chimiques sur le sang humain, Paris, 1837, as quoted by Valentin, Repertor. 1838, p. 230.

State in which iron exists in blood.—Menghini asserts that blood dried and powdered is affected by the magnet, by virtue of the iron which it contains; while, according to Sir C. Scudamore, the red colouring matter, when calcined, is not so affected. None of the common and most delicate tests for oxide of iron,—as ferrocyanate of potash, tannin, gallic acid, and the strongest mineral acids,—detect the slightest traces of iron or phosphate of lime in the colouring matter before it is calcined: it appears, therefore, that the iron and calcium of the blood are not in the state of salts. The assertion of Fourcroy, that the colouring matter is a solution of subphosphate of the peroxide of iron in albumen, and that the iron contained in the chyle is neutral phosphate of the protoxide of iron, is proved by the experiments of Berzelius to be incorrect; for the subphosphate of the peroxide of iron is insoluble in serum and in albumen, whether with or without the addition of an alkali. The opinion of MM. Prevost and Dumas, that the colouring matter is albumen containing peroxide of iron in solution, appears to be also incorrect; for the mineral acids and aqua regia should extract the iron from the uncalcined colouring matter[‡] if such were its constitution.

Engelhardt[§] has made some important discoveries relative to the share of the iron in producing the red colour. He first showed that a solution of the colouring matter of the blood in water, when impregnated with sulphuretted hydrogen, after a time loses its colour, becoming first violet, then green. This is exactly the effect which the same gas has on iron; and the experiment therefore seems to prove that this metal contributes to the production of the red colour. Engelhardt also found that all the iron, magnesium, and phosphorus, can be extracted from the watery solution of colouring matter, or from the coagulated colouring matter suspended in water, by passing a stream of chlorine through the fluid, or by mixing it with a solution of chlorine in water. The solution of colouring matter becomes at first greenish, and then quite colourless; the animal matter is precipitated in white flocculi combined with chlorine or hydrochloric acid; while the iron, calcium, magnesium, and phosphorus remain in the solution, combined either with oxygen or with chlorine,—the iron, for example, in the state of chloride of iron, the phosphorus as phosphoric acid,—and may be separated from it by filtration. The precipitated animal matter yields no ashes by calcination. Now chlorine has no affinity for oxides, but has a very strong affinity for metals. Moreover, iron is not extracted from the blood by muriatic and other mineral acids, which have a great affinity for metallic oxides, but none for the metals themselves. Hence Berzelius considered it more probable that the iron in the blood is in the metallic state, not in the state of an oxide, although there is no analogous instance known of a quinary combination of a metal with nitrogen, carbon, hydrogen, and oxygen.

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[*] A gramme equals 15·438 grains avoirdupois.

[†] Schweigger, Journ. lviii. p. 481.

[‡] Berzelius, loc. cit. p. 58.—French translation, p. 61.

[§] De vera materiæ sanguini purpureum colorem impertientis naturâ. Göttingen, 1825.

M. Rose* has lately adduced new facts in support of the opinion, that the iron contained in the blood is in the condition of an oxide. Rose repeated Engelhardt's experiment. By filtering the fluid after the change effected by the chlorine, and after the precipitation of the animal matter, he was able to separate the iron, while if, instead of filtering, he added to the fluid an excess of ammonia, all the precipitate was again dissolved and a dark red colour produced, and no iron was thrown down. Rose then mixed a solution of colouring matter with a certain quantity of a persalt of iron, and added ammonia in excess, when the peroxide of iron remained in solution, and could be separated neither by sulphuretted hydrogen nor tincture of galls. Rose found, moreover, that when a persalt of iron is mixed in small quantity with a solution of many fixed organic substances, such as sugar, gum, starch, sugar of milk, and gelatine, the peroxide cannot be precipitated from the fluid by alkalies. These experiments are certainly in favour of the supposition, that the iron in the colouring matter of the blood is in the state of an oxide combined with animal matter. Berzelius, however, is of opinion that the kind of combination which in the experiments of Rose retains the oxide of iron dissolved in the albumen or colouring matter, is not that by which it exists naturally in the colouring matter of the blood; because, were that the case, the iron would be extracted from the latter by acids, as it is from such artificial compounds of colouring matter or serum with peroxide or protoxide of iron. When a mineral acid is added to such an artificial compound, the colouring matter or albumen is precipitated, and the oxide dissolved in the acid.

Berzelius believes, therefore, that the iron in the colouring matter is in the metallic state "organically" combined with nitrogen, carbon, hydrogen, and oxygen, together with a small quantity of phosphorus, calcium, and magnesium; and that by calcination of the colouring matter its elements are oxidised, so as to form phosphoric acid, lime, magnesia, and peroxide of iron. The state of the iron in the chyle seems also to favour this view; for it must there be in quite a different state,—namely, in the state of peroxide,—since Emmert† has found that it is extracted by nitric acid; and forms then with tincture of galls a black, with ferrocyanate of potash a blue, precipitate.

Meanwhile Gmelin‡ opposes the view which attributes the red colour of the blood principally to the iron, though he does not deny that iron in the metallic state is combined with nitrogen, carbon, oxygen, and hydrogen, in the colouring matter.

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* Poggendorf's Ann. vii. 81.

† Reil, Archiv. 8.

‡ Gmelin, Chemie, iv. 1169.

Treviranus has offered a peculiar view of the condition of the iron in the blood. He supposes that the substance, called by Winterl,—who procured it by carbonising blood with potash,—*sanguineous* acid, combined with iron, is the cause of the red colour of the blood.

Hermbstaedt,[*] recently, from observing that sulphuretted hydrogen is developed during the putrefaction of blood and albumen, as well as from several experiments, has been led to the conclusion that sulphur is a colouring ingredient in the blood. His explanation is, however, devoid of all probability.

Of the liquor sanguinis.

The *liquor sanguinis,*—the fluid portion of the blood in which the red particles float during life,—separates, when coagulation takes place, into two parts,—the *serum,* and the *fibrin* which was previously in solution. The fibrin coagulating encloses within it the red particles. The serum still retains the albumen in solution. We shall treat first of the *fibrin.*

1. *Of the state in which fibrin is found in the blood.*

Conflicting opinions have been held respecting the relation of the fibrin to the red globules, and its solution in the fluid part of the blood. Sir Everard Home, and Prevost and Dumas, caused physiology to retrograde when they taught that the coagulation of the blood resulted from the aggregation of the red particles, and that these latter are merely globules of fibrin in an envelope of red colouring matter. Hewson long ago showed the real state of fibrin to be that of solution in the fluid part of the blood.[†] Berzelius subsequently observing that the lymph contains fibrin in solution, conjectured that the blood also must contain this latter in that state; and hence he suggested that the clot was formed by the fibrin coagulating and enclosing the red particles. I have satisfied myself by experiments that this is a correct view of the case, and that fibrin as well as albumen, is really dissolved in the *liquor sanguinis.* After other experiments, I had recourse to the following unquestionable mode of demonstrating this fact. Knowing that the red particles of frog's blood are four times the size of those bodies in the blood of mammalia, I conjectured that, although the red particles of the latter animals pass through filter paper, those of the frog might not; and I found this opinion correct. Thus, as generally happens, the most simple means was the last thought of. I am now enabled to show at lecture by an easy experiment, that fibrin is held in solution in the blood; that it passes limpid through the filter, and then coagulates. The experiment can be made on quite a small scale with the blood of a single frog; a small glass funnel and a filter of common white filtering paper, or not very thick printing paper, being all the apparatus required. The filter must, of course, be previously moistened; and it is better to add some water to the blood as soon as the latter is poured into the filter. What then passes through is a perfectly clear serous fluid diluted with water, and merely tinged in the slightest degree by the red colouring matter, which in frog's blood is not rapidly dissolved. Sometimes it is quite colourless. Of course, all the fibrin of the blood is not separated by this process; the greater part of it coagulates before it can pass through the filter. To find the paper best adapted for the filter, some trials must be made with different kinds. If the paper is too thin, some few red particles pass through it with the fluid, and will afterwards be seen here and there in the coagulum. If the paper is of the proper thickness, the coagulum will not contain a single red particle.

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[*] Schweigger's Journ. 1832, v. and vi. 314.

[†] In England this has been not merely the opinion of individuals, but, before physiologists were led astray by the incorrect observations of Sir Everard Home and MM. Prevost and Dumas, was the one generally held and taught in the schools. —See Hewson's Experimental Inquiries, part i. *passim.*—Hunter's Treatise on the Blood, p. 16 *et sequent,* (Mr. Palmer's edition.)—Dr. Gordon's Outlines of Lectures on Human Physiology, 1817, p. 60,—and the translator's note at page 110 of the former edition of this work.

There is still another mode of proving that fibrin exists dissolved not only in the blood of the frog, but also in that of mammalia. By adding to the blood of man or any vertebrate animal some drops of a very concentrated solution of carbonate of potash, coagulation is retarded, so that the red particles have time to subside. In the space of half an hour a soft coagulum forms, of which the lower part containing the red particles is red, while the upper is white. This experiment was performed by Mr. Hewson.

Proportion of fibrin in the blood.—We are indebted to MM. Prevost and Dumas for an attempt to calculate the amount of the red particles in the blood of different animals, from the weight of the crassamentum when dried. But, as Berzelius has remarked, the result of such calculations can never be exact; because the crassamentum contains a large quantity of serum, the albumen and salts of which must be left behind during desiccation; and if the coagulum were washed, not only the serum, but the red colouring matter also would be removed. It must likewise be remembered, that Prevost and Dumas consider the fibrin to be wholly derived from the red particles, so that what they speak of as the amount of red particles, must be regarded as the sum of the red particles and fibrin together. With this correction, their numerous calculations of the proportional weight of the different component parts of the blood are of value. The same remarks apply also to the otherwise excellent researches of Lecanu, with regard to the quantity of the red particles in the different temperaments and sexes.

To determine the quantity of fibrin in the blood of different animals and in different diseases, new experiments are required. The best mode of ascertaining the quantity of fibrin is by briskly stirring the blood with a rod or bunch of twigs, when the fibrin separates in the form of a colourless or nearly colourless coagulum, and leaves the blood of its natural colour; the red particles floating in it having undergone no change, provided that water had not been added.

This is the only method by which the red particles can be separated in their perfect state from the fibrin. If the fluid parts are strained off through a linen cloth, and the solid fibrin washed so as to purify it from serum, the weight of fibrin contained in a certain quantity of blood can be accurately determined. The exact proportion of red particles cannot be ascertained.

The only point which I have investigated, is the proportion of fibrin in the blood, this being the only one which can be determined with accuracy. From 3627 grains of bullock's blood I obtained, by stirring, 18 grains of fibrin. The crassamentum of 3945 grains of the same blood weighed, when dried, 641 grains. So that in 100 parts of the blood of this animal there were 16·248 parts of dry crassamentum and 0·496 parts of fibrin. Fourcroy estimates the quantity of dry fibrin in 1000 parts of blood at from 1·5 to 4·3. Berzelius calculated that it was 0·75; while Lassaigne found it to be 1·2. In twenty-two experiments Lecanu found the proportion of dry fibrin in 1000 parts of human bloed to vary from 1·360 to 7·235 parts.*

Proportion of fibrin and red particles in arterial and venous blood.—Prevost and Dumas state, as the result of their experiments, that arterial blood contains more red particles than venous blood; meaning of course, that it contains more crassamentum. Arterial blood would be expected to contain more fibrin; because the material for the nutrition of the body is derived from arterial blood, and the lymph and chyle, both of which contain fibrin in solution, are being constantly poured into the central parts of the circulating system. The result of several experiments instituted by Mayer, Berthold, and myself, agreed with this supposition. The mean result of these is, that the quantities of the fibrin in arterial and venous blood are in the proportion of 29 to 24.

The substance which has been subjected to chemical analysis under the name of fibrin of the blood, is the matter which, while the blood is circulating, is in a state of solution, and coagulates when the blood is removed from the body. When obtained by stirring the blood, it is pure; but if procured by washing the coagulum, it may also contain the nuclei of the red particles. The proportion which these bodies form in it, cannot, however, be very great; for there is scarcely any difference in weight between the coagulum when deprived of its colouring matter by washing, and the fibrin obtained from the same quantity of blood by stirring. Whether the nuclei which I obtained from frog's blood consist of fibrin or not, is difficult to say; they have the more general properties of coagulated fibrin and albumen.

Coagulation of inflammatory blood.—In inflammation, and under some other circumstances, the blood coagulates in an unusual manner. Before coagulation commences, the red particles subside to a certain extent, leaving the upper part of the still fluid blood colourless or milky; and the upper layer of the gelatinous coagulum, which soon afterwards forms, is white or of a grayish yellow colour, while the lower part is red. During the contraction of the coagulum, these two portions of the clot diminish unequally in size; the upper whitish or grayish yellow substance contracts more firmly; and, although at first the coagulum occupied equally at all heights the entire diameter of the vessel which contains it, the whitish portion acquires at length a much smaller diameter than the red portion, and thus arises the peculiar form of the coagulum of inflamed blood. The cause of the unequal contraction of the two parts of the crassamentum is, that in the lower portion the fibrin is kept mechanically extended, as it were, by the red particles which it contains, while in the upper there are none of these bodies to prevent its close contraction. It must, however, be understood that fibrin is present and coagulates in all parts of the clot. The formation of a buffy coat may always be predicted before coagulation; for the subsidence of the red particles being a necessary condition, the surface of the blood is observed to become first transparent, and afterwards to acquire an opaline aspect. Mr. Hewson and Dr. B. Babington* have shown that the colourless fluid which produces this appearance can be removed with a spoon, and that it afterwards coagulates. This fact I have seen verified on the blood of a pregnant woman.

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* Lecanu, Transact. Med. 6 Oct. 1831, 92.

Cause of the buffy coat.—This peculiarity of the blood under certain circumstances, namely, the subsidence of the red particles to a certain extent before coagulation, might be supposed to depend on diminished specific gravity of the serum, were it not that the serum of inflammatory blood has the same specific gravity as that of healthy blood. The fact that inflammatory blood ordinarily coagulates more slowly than healthy blood may in some measure explain the phenomenon; for it may be imagined that the red particles have, on that account, sufficient time to subside before the fibrin coagulates. This was the view that Hewson took of the formation of the buffy coat. To ascertain the correctness of this mode of explaining the phenomenon, I instituted a series of experiments with different kinds of blood. Among other confirmatory results, I found that by merely retarding the coagulation, I was able to give rise to the process by which the inflammatory crust is formed; the only difference being, that the fibrin which formed the artificial crust was softer and more glutinous; which depended, perhaps, on some chemical change effected by the carbonate of potash. There is another cause, for the greater firmness of the inflammatory crust; it is, that inflammatory blood contains more fibrin than healthy blood,—a fact which Sir C. Scudamore ascertained. It is difficult to say why the red particles should begin to subside in healthy blood as soon as it is drawn from the body, and yet sink so very slowly in blood deprived of its fibrin, even though it be inflammatory. The relative specific gravity of the serum and liquor sanguinis cannot be the cause; for the blood when deprived of its fibrin is specifically lighter than it was before. It may be that there is less adhesion exerted between the red particles and the liquor sanguinis, which still holds the fibrin in solution, than between the red particles and the serum without the fibrin.

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* Medico-chirurgical Transact. vol. xvi. p. 11.

Dr. J. Davy has observed, that inflammatory blood, in some instances, does not coagulate more slowly than healthy blood; and since the presence of fibrin in the blood appears from the abovementioned experiments to favour the subsidence of the red particles, the formation of the buffy coat in these cases may arise from the blood containing a greater quantity of fibrin. So that the principal causes of the subsidence of the red particles and formation of the buffy coat in inflammatory blood appear to be its slow coagulation and the increased quantity of fibrin which it contains. The formation of a loose crust on the crassamentum in cases where we suspect a commencing disorganisation or decomposition of the blood, rather than the presence of an increased quantity of fibrin, is sufficiently explained by the slow coagulation of such blood.* For the chemical characters of the fibrin, the reader is referred to Book I. p. 98–100.

OF THE SERUM.

The fluid which remains after the coagulation and contraction of the fibrin of the blood, is called the serum; and, as we have before remarked, must not be confounded with the *liquor sanguinis.* It is yellowish, has a saline taste, a specific gravity of 1·027 to 1·329, and in the higher animals, a distinct alkaline reaction. When exposed to a temperature between 158° and 167° Fahr., whether *in vacuo* or in the atmosphere, it is converted into a gelatinous mass by the coagulation of the albumen, which is its most essential component. It contains, also, a free alkali,—soda, (potash, likewise, according to Berzelius,)—probably combined with albumen and salts of these bases. We are indebted to Prevost and Dumas for a table, showing the proportional quantity of the solid components of the serum and the other ingredients of the blood in different animals. From this table it appears, that in the serum of human blood about one-tenth part in weight consists of solid ingredients in solution, the chief of which is albumen; and that this relative proportion is pretty nearly maintained even as low in the animal scale as fishes: while the proportional quantity of the coagulum, fibrin, and red particles in the blood, is less in fishes and amphibia than in the higher classes.† The proportion of the solid parts of the crassamentum to those of the serum in human blood is as 12·92 to 8·69, or about 3 to 2. The blood of carnivorous animals yields more crassamentum than that of herbivorous animals. Dr. Davy states, that the blood of the lamb affords a softer and less abundant coagulum than the blood of the full-grown sheep. I have verified Fourcroy's statement, that the coagulum of fœtal blood is softer than that of the blood of the adult animal. From Berthold's‡ experiments it appears that the quantity of fibrin in the blood of cold-blooded animals, is as great as in that of warm-blooded animals, while the colouring matter is less in quantity.

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* On the subject of the inflammatory or buffy coat, consult H. Nasse, Das Blut. Bonn, 1836.

† The exception in the tortoise in the table of MM. Prevost and Dumas, has been shown by Mr. J. Marshall's experiments not to exist.

‡ Beiträge zur Anat. Zool. und Physiol. Gött. 1831.

If serum is exposed to a temperature not lower than 75° R. [167° Fahr.] it coagulates into a solid mass, which consists principally of albumen. From this mass exudes a brown fluid, the "serosity," which, according to Gmelin, is rendered turbid by the addition of acids, and becomes somewhat gelatinous on cooling. The components of this fluid, according to the same chemist, are, besides albumen held in solution by an alkali,* casein, salivin, osmazome, and salts of soda and potash. The casein was found by Gmelin and Geigert, in another experiment, in the blood of the ox also. Serum of the blood of that animal, from which the fibrin had been removed by stirring, having been boiled for a considerable time with alcohol, the fluid obtained from it by filtering deposited in cooling copious flakes, which consisted of casein mixed with ammonia and cholesterine.

If serum be completely coagulated by the action of heat, the coagulum dried, and then treated with boiling water, and the residuum left on evaporating the solution thus obtained afterwards acted on repeatedly with alcohol, the alcohol will be found to take up lactate of soda, chlorides of potassium and sodium, and osmazome; while the substance, which neither the boiling water nor alcohol dissolves, is pure albumen. The animal matters of the serum are, therefore, salivin, casein, lactic acid, osmazome, and albumen.

1. *Salivary matter or Salivin.*—This substance, which derives its name from the saliva, is not peculiar to it; but is found in various other secretions, in the fluid effused in several dropsical affections, and in that of the vesicle excited by plaster of cantharides. It is soluble in water, both warm and cold, but insoluble in alcohol; is precipitated neither by the metallic salts nor by strong acids, and its solution is not rendered turbid, or only in a slight degree, by infusion of galls.

2. *Casein* occurs in great abundance in milk; and, according to Gmelin, in smaller quantity in the pancreatic secretion and in the bile. It is soluble both in hot and in cold water; is slightly soluble in cold, but more so in hot alcohol; and is precipitated by muriate of tin, acetate of lead, bi-chloride of mercury, and infusion of galls. Acetic acid and the mineral acids precipitate it; but added in excess, redissolve it. It is precipitated by alum, and not redissolved by an excess of that reagent. The acid solution of casein is like the albuminous class of substances precipitated by ferrocyanuret of potassium. The precipitates of casein by acids and alcohol are again soluble in water, a character which distinguishes casein from albumen. The coagulation by the digestive principle or pepsin contained in the fourth stomach of the ruminantia, and in the stomach of other animals, is also characteristic of casein. The precipitate by pepsin is not soluble in water.

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* Mr. Brande also found albumen in the serosity, while Dr. Bostock maintains that the only animal matter contained in that fluid is osmazome. See Bostock's Physiology, p. 292; 3d edition.

3. *Lactic acid.*—This acid is composed of carbon, hydrogen, and oxygen; it has some analogy with acetic acid, but according to Berzelius is quite distinct from it. It forms with bases, salts of peculiar form, which Berzelius says, are not produced by acetic acid rendered impure by animal matter. Pure lactic acid, prepared by the method most recently described by Berzelius, is colourless, without smell, and has a pungent acid taste, which is very quickly diminished by the addition of water. It is soluble in alcohol in all proportions, while ether dissolves it in small quantity only. It is found in muscle and in the crystalline lens; and, with its salts, occurs in many secretions, particularly in the milk. Lactic acid and its salts, are always combined with osmazome, and are extracted together with it by alcohol, but can be separated from it by means of infusion of galls, which precipitates the osmazome.

Osmazome, albumen, and the fatty matter of the blood, have been already described in book first, under the head of Component Proximate Principles of the Tissues.

COMPOSITION OF THE BLOOD IN THE DIFFERENT SEXES, AGES, AND TEMPERAMENTS.—This inquiry, originated by Lecanu, constitutes a new epoch in this department of Physiological Chemistry. Lecanu* seems to have made an extraordinary number of observations, and to have compared them with accuracy. He found the quantity of water in 1000 parts of blood to vary from 778·625 to 853·135, the average being 815·880. In the female it varied from 790·394 to 853·135; in the male, from 778·625 to 805·26. So that the blood of the female contains the greater proportion of water. This was the result also of Denis's experiments, of which twenty-four were made on men, and twenty-eight on women. The latter author found the proportion of water in man to vary from 805 to 732; in woman, from 848 to 750: the mean proportion of the two being as 767 to 787. The quantity of water in the blood, according to Lecanu, bears no determined relation to the period of life; Denis, however, found its proportion greater in children and aged persons. With respect to the temperaments, Lecanu found that, in the sanguine temperament, the blood contains less water than it does in the lymphatic. In women of sanguine temperament, the proportion of water in four experiments varied from 790·394 to 796·175 in 1000 parts of blood; in women of phlegmatic temperament, it was found as the result of five experiments to vary from 790·840 to 827·130. The average in women of sanguine temperament was therefore 793·007; in those of the phlegmatic 803·710. From similar observations on men, the average for those of the sanguine temperament of this sex was found to be 786·584; for those of the phlegmatic, 800·566. Thus, in the female sex, the excess of water in the phlegmatic temperament is 10·703; in the male it is 13·982.

The proportional quantity of albumen varies in general from 57·890 to 78·270, and is nearly equal in the two sexes; it does not vary in any determinate degree between the ages of twenty and sixty, nor is there any striking difference in its quantity in the different temperaments.

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* Beiträge zur Anat. Zool. und Physiol. Gött. 1831.

The quantity of crassamentum in 1000 parts of blood varies generally from 68·349 to 148·450, the average being 108·399. In men it varies from 115·850 to 148·450, in women from 68·349 to 129·990; so that, according to Lecanu, the blood of men contains, in 1000 parts, about 32·980 parts more of the components of the crassamentum than the blood of women. The quantity of the coagulum does not appear to increase proportionally with the age, at least not between the ages of 20 and 60 years; but it is greater in the sanguine than in the phlegmatic temperament—a result which agrees with Denis's observation. In four observations on women of sanguine temperament, the proportion of coagulum in 1000 parts of blood, varied from 121·720 to 129·654; in five observations on women of phlegmatic temperament, from 92·670 to 129·990; the average in women of sanguine temperament being 126·174, in those of the phlegmatic 117·300,—making a difference of 8·874 between the temperaments. In men of the sanguine temperament the proportion of coagulum, in five observations, varied from 121·540 to 148·450; in those of the phlegmatic temperament, in two observations, it was 115·150 and 117·484.

During menstruation Lecanu found that the blood contained less coagulum.

CHAPTER II.

Electric Properties of the Blood.

Dutrochet has made some ingenious experiments respecting the action of galvanism on animal substances. He even flattered himself that he had formed muscular fibres from albumen by the agency of galvanism, and supposed that the red particles of the blood formed each a pair of plates, the nucleus being negative, the envelope positive.* But all the appearances which he has attributed to different electric properties of the blood, are explicable by the precipitation of the albumen, colouring matter, and fibrin in consequence of the decomposition of the salts of the serum, and of the oxidation of the copper wire used in the experiments,—both the decomposition of the salts and the oxidation of the copper being the usual effects of galvanic action.†

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* Annal. des Sc. Nat. 1831.—Froriep. Notiz. 716.

† Brief reference has been already made (p. 73) to Bellingeri's assertion respecting the alleged electric properties of the blood.

CHAPTER III.

OF THE ORGANIC PROPERTIES AND RELATIONS OF THE BLOOD.

a. The Vivifying Influence of the Blood.

The arterial blood in its course through the capillary vessels of the body, loses its bright red colour, and becomes again venous. The reciprocal action between the blood and the organised matter, by which this change is effected and maintains the vitality of the organs, at the same time that it renders the blood incapable of again exercising this necessary vital stimulus until it has regained its arterial character in the lungs is, unknown. In the process of arterialisation, the blood absorbs oxygen from the atmosphere, and gives out carbonic acid,—the oxygen which it absorbs being in greater quantity than the carbonic acid exhaled. The same portion of blood acquires and again loses its arterial properties within the period of a few minutes; for it will be shown at a future page, that the blood circulates through the whole body in that space of time. It is only while in its arterial state that the blood is capable of maintaining life. The suppression of the change which the blood undergoes in the lungs produces asphyxia and death, chiefly, as Bichât has shown, by interrupting the functions of the brain and nervous system. The necessity for arterial blood is less urgent, however, in new-born children, and still less so during the state of hybernation and torpor, and in the lower animals; in the fœtus of the Mammalia the necessity for the aeration of the blood seems to be wholly wanting. The functions most dependent on the arterial state of the blood, are those of the nervous system, and those of animal life generally. This is evidenced by the symptoms of the *morbus cœruleus*, in which the two kinds of blood, owing to some defect in the circulating organs, —for instance, a persistence of the canal in the *ductus arteriosus*, or of the *foramen ovale*,—continue to be partly mixed. Nutrition and secretion are here little interfered with, even although the surface is dusky and bluish: but the muscular power fails; the slightest exertions bring on symptoms of suffocation, fainting, and even asphyxia; the sexual passion is not developed, the temperature is lower than natural, and there is a tendency to hemorrhage, even to a fatal extent.* That arterial blood is not so necessary for the performance of the functions of organic life is moreover deducible from the fact that secretions are, in some cases, formed by organs which receive a much larger quantity of venous than of arterial blood. Thus the bile is secreted in part from the blood of the vena porta, the urine in reptiles and fishes in greater part from the venous blood which in these animals is carried to the kidneys by afferent veins independent of the arteries, and of the efferent veins that return the blood to the heart.

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* Consult Nasse's remarks on the influence of arterial blood on the development and functions of the human body, founded on cases of the morbus cœruleus. —Reil, Archiv. t. x. p. 218.

The application of a ligature to all the arterial trunks of a limb deprives it of power of motion, and at last of vitality. Sir A. Cooper has shown* that rabbits may be killed instantaneously by exciting pressure upon the vertebral arteries and carotids simultaneously, so as to cut off the supply of arterial blood to the brain. Great losses of blood produce immediate asphyxia in the higher animals: cold-blooded animals, however, survive for a considerable time the abstraction of the greater part of their blood, and frogs live many hours even after the removal of the heart, and retain perfect power of motion. But even parts which have been removed from the body, and have lost their irritability, appear to recover in some degree their vitality by immersion in blood, as in the case of the heart of the frog in Von Humboldt's experiments; and the motion of the microscopic cilia on portions of mucous membranes separated from the body is, according to the observation of Purkinje and Valentin, maintained longest by immersion in blood.

Transfusion of blood.—Prevost and Dumas showed that the vivifying power of the blood does not reside so much in the serum as in the red particles. An animal bled to syncope, is not revived by the injection of water or pure serum of a temperature of 68° Fahr. into its vessels. But if blood of another of the same species is used, the animal seems to acquire fresh life at every stroke of the piston, and is at last restored. Professor Dieffenbach has confirmed these experiments. It is stated by Prevost and Dumas, and Dieffenbach, and also by Dr. Bischoff,† that revival takes place likewise when the blood injected has been previously deprived of its fibrin. I have shown that the red particles of the blood remain perfectly unchanged after the removal of the fibrin; blood, therefore, from which the fibrin has been removed, and heated to the proper temperature, ought to be preferred in a few cases where transfusion of blood in the human subject is justifiable, or necessary, on account of hemorrhage; for in this state the blood is completely fluid and remains so, and thus the principal difficulty of transfusion,—namely, the coagulation of the blood while it is being transferred from one animal to the other,—is avoided. Blood of animals of a different genus, of which the corpuscules, though of the same form, have a different size, effect an imperfect restoration, and the animal generally dies within the period of six days. The pulse becomes quicker; the breathing remains natural, though the temperature sinks very rapidly; the excretions are mucous and bloody; while the cerebral functions seem to be unaffected.

The injection of blood with circular corpuscules into the vessels of a bird (of which the corpuscules are elliptic and of larger size), produces violent symptoms similar to those of the strongest poisons, and generally death, which ensues, indeed, instantaneously, even when a small quantity only of the blood has been injected; such, for example, was the effect of the transfusion of some blood of the sheep into the veins of a duck. The results which Dr. Bischoff obtained in his experiments differed from those of former observers, in the circumstance that he found no ill effect from the injection of the blood of mammalia into the veins of birds if he had previously deprived it of its fibrin. But even blood thus prepared was poisonous to frogs, particularly human blood: the blood of quadrupeds and birds was less violent in its action; that of fishes seemed to have little ill effect. The transfusion of the blood of man, mammalia, or birds into the veins of the frog was always followed by death, generally in the space of a few hours. The circulation was in all cases much enfeebled. After death there were found exudations of serum mixed with red particles both of the blood injected and of that of the frog itself.[*] According to later experiments of Dr. Bischoff,[†] it is the venous blood only of mammalia which is poisonous to birds; arterial blood of a mammiferous animal injected into the vessels of a hen, produced no ill effect, while a few drops of venous blood were immediately fatal.

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* Guy, Hospital Reports, vol. i.

† Müller, Archiv. 1835, p. 347.

An incautious injection of air into the veins and blood of a living animal is almost immediately fatal, by obstructing the circulation in the small vessels, and in the heart. Nevertheless, in Nysten's experiments, very small quantities, not only of atmospheric air and oxygen, but even of irrespirable gases, such as nitrogen, nitrous oxide, hydrogen, carburetted hydrogen, carbonic acid, and carbonic oxide, were injected into the vessels without fatal consequences. Nitric oxide gas, sulphuretted hydrogen, ammonia, and chlorine, were the only gases which he found to be absolutely deadly.[‡] Recent experiments[§] have confirmed the observation, that the injection of a considerable quantity of atmospheric air is required for the production of death in horses and dogs, and that the fatal result is, in these animals, by no means so instantaneous as it has been in the human subject, when, during operations, air has gained entrance into the veins. The insufflation of respired air seems to be more quickly fatal than the injection of fresh atmospheric air. The most probable cause of death, when it follows the injection of a large quantity of air, is apparently paralysis of the right cavities of the heart, which in nearly all the experiments have been found distended by frothy blood, or unmixed air, while the left cavities of the heart generally contained no air. Mr. Blake[||] has ascertained that certain salts injected into the veins, cause death very quickly by arresting the heart's action: such seemed to be the mode of action of salts of potash, ammonia, baryta, lime, and magnesia, while the salts of soda produced death with equal rapidity by obstructing the circulation through the lungs.

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[*] Compare Die Transfusion des Blutse, von Dieffenbach. Berlin, 1828.

[†] [Müller's Archiv. 1838, p. 352.]

[‡] Nysten, Recherches de Physiol. et de Chim. Pathol. Paris, 1811.

[§] See Rapport sur les Expériences relatives à l'introduction de l'air dans les veines, faites par M. Amussat.—Bulletin de l'Acad. de Médecine, t. ii. No. xii.—Velpeau, Gazette Médicale, Feb. 29, 1838.—Dr. Cormack, on the presence of air in the organs of circulation. Edinb. 1837.—Also an able review of these works in Dr. Forbes's British and Foreign Medical Review, No. xii.

[||] See the Medical Gazette, July 29, 1839, and the Edinb. Med. and Sur. Journal for April, 1839.

b. Evidences of life in the blood itself.

Automatic movements of the blood-corpuscules.—It is beyond dispute that the blood must be regarded as a living fluid, but hitherto observers have failed to detect a vital act in it as a visible phenomenon. Professor C. H. Schultz has spoken of an active vital process which can be seen to be constantly going on, between the individual molecules of the blood and the substance of the vessels, by which new globules are formed, while the old are lost.* More recently Professor Schultz has stated more definitely that the blood particles themselves do not move, and that the flickering vibratory motion (which is seen when the circulation in transparent parts is viewed by the direct light of the sun) is due to the fluid part of the blood. This oscillatory motion is visible, according to Schultz, in the smallest capillaries, even when they contain no red particles.† These observations are quite opposed to the experience of other observers, while Rudolphi, Purkinje, and Koch, with Meyen, and myself, all agree as to the true explanation of the appearance which Schultz calls a vital movement of the blood. When the circulation of the blood is viewed in transparent parts by bright daylight, (not by the direct rays of the sun, which produce a dazzling but very confused illumination, from their being refracted by the transparent animal structures,) there is not the slightest appearance of spontaneous independent motion of the individual red particles, of attraction and repulsion of them, or of the minute molecules of liquor sanguinis. If, however, the direct rays of the sun are allowed to shine through a transparent part, the distinctness of the image is entirely lost, owing to the refraction of light which is produced by the inequalities of the surface, as well as by the red particles, which act as so many little lenses; the observer no longer perceives the red particles flowing through the vessels, but there is a general, sparkling, flickering motion, in which frequently even the direction of the current is not distinguishable. The same deception of vision is produced, when a fluid containing globules—milk, for example—is viewed while flowing over the surface of a glass under the microscope, by the direct rays of the sun; and even clear water flowing over the surface of ground glass has, by a similar light, the same appearance.‡ The granular substance of the animal tissues may be compared to the surface of ground glass.

The notion of Eber and Mayer,§ that the red particles are infusory animals, is still less admissible. The theory which ascribes to the blood a self-propelling power—a power of motion, which continues when the heart has ceased to act—will be considered in treating of circulation in the capillaries.

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* C. H. Schultz, der Lebensprocess im Blute. Berlin, 1822.

† C. H. Schultz, das system der circulation. Stuttgart. 1836, p. 74.

‡ Meyen, Isis, 1828, 394, and the review by an anonymous writer—Isis, 1824, 3.—are especially worthy of being consulted on this subject.

§ Mayer, Supplemente zur Lehre vom Krieslauf. Bonn. 1827.

Treviranus, Mayer, and others have regarded, as an automatic movement, that confused motion of the globules which is seen to continue for several seconds in a drop of blood placed on a glass under the microscope. The fallacy of this opinion is, however, completely proved by the fact, that these momentary whirling motions can be seen in blood which has been long removed from the body. Thus, for example, in a drop of frog's blood which has been taken from the animal twelve or twenty-four hours, and from which the fibrin has been removed, we can distinguish by means of the microscope the same motions of the red particles as in fresh blood; they cannot, therefore, be dependent on vitality. In the blood of warm-blooded animals such motions may also arise from evaporation. It is probable, likewise, that the slight, but sometimes rapid, change of form which every drop of fluid spread on a glass plate undergoes at the edges, has considerable influence on these motions. That blood-corpuscules lying near the surface of ciliated membranes, such as the mucous membranes of the generative and respiratory organs, are like all other small bodies thrown into motion, is easily intelligible.

Motion in blood during its coagulation.—Heidmann* has described contractions and dilatations which he has observed in the blood during coagulation. I have myself, however, been able to detect no dilatation, and no other contraction than the gradual imperceptible contraction of the coagulated fibrin. The contractions which Tourdes and Circaud described as produced in the fibrin by galvanism ,have been proved, even by Heidmann himself, not to exist, and I certainly saw nothing of the kind in galvanising the liquor sanguinis of the frog's blood.

Is the blood endowed with life?—The question whether the blood is a living fluid or not, calls to mind a critical state of our science. Everything which evidences an action that cannot be explained by the laws of inorganic matter, is said to have an organic, or, what is the same thing, a vital property. To regard only the solids of the body as living is incorrect, for there are strictly no organic solids; in nearly all, water constitutes four-fifths of their weight. Although then organic matter generally be considered as merely "susceptible of life," and the organised parts as "living," yet the blood also must be regarded as endowed with life, for its actions cannot certainly be comprehended by chemical and physical laws. The semen is not merely a stimulus for the fructification of the egg, for it impregnates the eggs of the batrachia and fishes out of the body; and the form, endowments, and even tendencies to disease of the father, are transferred to the new individual: the semen, therefore, although a fluid, is evidently endowed with life, and is capable of impartiag life to other matter. The germinal membrane is a completely unorganised aggregation of animal matter, and nevertheless is animated with the whole organising power of the future being, and is capable of imparting life to new matter, although soft and nearly allied to a fluid. The blood also manifests organic properties; it is attracted by living organs which are acted on by vital stimuli; there subsists between the blood and the organised parts a reciprocal vital action, in which the blood has as large a share as the organs in which it circulates. The fibrin of the blood effused in inflammation is at first fluid, and forms, as it becomes solid, pseudo-membranes, which afterwards, by means of a mutual vital action exerted between them and the organs by which they are poured out, become organised and traversed by blood and vessels. The blood itself has, therefore, the properties of life, and this is the case with all the animal fluids except those which are the means of carrying out of the body the effete material, such as the urine and carbonic acid. The saliva and the bile exert an assimilating action on the food, the different organs perform the same functions with regard to the blood, and here there is no clearly defined limit between substances capable of life and those endowed with it. Those organic substances, however, in which life is least evident, remain susceptible of life as long as they are not chemically changed.

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* Reil, Archiv. vi. 425.

c. *Formation of the Blood.*

The materials for the formation of the blood are the lymph and chyle. The former fluid yields the nutritive matters taken up from the intimate structure of the organic body; the latter, those absorbed from the intestinal canal. Both are poured into the blood by the thoracic duct. The lymph and chyle contain albumen and fibrin in solution, but these substances are in less proportion in them than in the blood. The lymph has so great a resemblance to the *liquor sanguinis,* that the latter fluid may be correctly termed the lymph of the blood, while the blood may be regarded as lymph with red particles, or the lymph as blood without red particles. The chyme or digested food in the intestines contains albumen in solution, but no coagulating fibrin; the latter substance is formed in the absorbent system, and thence is poured into the blood. It is a remarkable fact, which I have observed to be nearly constant, that in frogs kept long without food, the blood frequently loses its property of coagulation, and that in these cases the lymph, which usually coagulates quickly like the blood, also does not coagulate. In winter, however, the blood of the frog often coagulates, although not completely; and here, as in all cases where the blood of this animal does not coagulate perfectly, the coagulation of the lymph is also not so firm. Lymph and chyle contain somewhat less solid matter than the blood, and especially less fibrin. Chyle is less distinctly alkaline than the blood. There is a certain quantity of uncombined fat in the chyle, which appears to become more intimately combined in the blood. Iron also is in a state of less intimate combination than in the blood, and can be detected, according to Emmert, by adding tincture of galls to chyle previously treated with nitric acid.

Autenrieth supposes that the chyle poured into the circulation, is converted into blood in the course of ten or twelve hours, because within this period the serum is frequently observed to be milky. It is probable, however, that the change is effected still more slowly; for, as I have already remarked, when the coagulation of the blood is retarded by the addition of sub-carbonate of potash, the supernatant fluid from which the red particles have subsided is often somewhat turbid and milky.

Origin of the red particles.—The scanty globules of lymph obtained from the lymph cavities under the skin of the frog are only about one-fourth of the size of the blood particles of that animal; while from the elliptical nuclei of the latter bodies they differ in their form, being spherical, and for the same reason they are still more unlike the very elongated nuclei of the red particles of the salamander's blood. Were it not for these differences, we might suppose the lymph globules to be the nuclei of future blood corpuscules, more especially as bodies exactly similar to them, and evidently identical with them, are found, mingled with the red particles, in the blood. The globules of the chyle of the higher vertebrata differ still more than these lymph globules from the red particles of their blood. It is exceedingly probable, however, that the lymph globules are the cells which afterwards become the red particles of the blood in an early stage of their development; just as the roundish cells of the *rete mucosum*, as observed by Henle, are an early form of the epidermis scales. It will be shown hereafter, that the lymph globules of the frog contain a nucleus; that this nucleus is apparently first formed, and that the cell or exterior part of the globule is afterwards developed around it and gradually enlarges, while the size of the nucleus remains the same. This corresponds exactly with the mode of formation of the primary cells of the epidermis and other tissues, in the manner already explained in Book First. The identity of the colourless spherical bodies with the globules of the lymph can scarcely be doubted; it only remains, therefore, to demonstrate, that the flattened and elliptical blood corpuscules are formed from them by the flattening and extension of the cell surrounding their nucleus, as the analogy of the process of development of the other organic elements of the body would lead us to suppose. It must be confessed that this is not yet absolutely certain, though there are several circumstances strongly corroborative of the opinion, such as the similarity of size between the nuclei of the lymph globules and those of the red particles, the presence in the blood of the frog of red particles smaller, more circular, and less flattened than the rest, and lastly, the fact observed by M. Schultz, that in the blood of the elephant there are bodies of various form, apparently representing states of transition between the colourless globule and the flattened red particle. That such intermediate forms are not more frequently seen may be accounted for, by supposing that the transformation of the globule into the disk takes place very rapidly at the same time that the red colour is acquired. The transformation of the round cells of the epidermis into the broad flat scales must, according to the observation of Schwann,* be very rapid, for in the embryo of the pig he could detect no forms intermediate between them. According to the observation of Prof. Weber, indeed, the red particles of the blood circulating in the capillaries under certain circumstances reassume for a time the globular form and colourless appearance of lymph globules. (See the account of the circulation in the capillaries.)

In what part of the system the red colouring matter or envelope of the red particles of the blood is produced, is quite unknown; it is not present in the chyle and lymph, a slight trace of it only being sometimes discoverable in the thoracic duct. Respiration seems to have a share in its production. Hewson's hypothesis, that the red colouring matter is formed in the spleen and in the lymph of the spleen, which is sometimes of a dirty red colour, is without foundation; the spleen having been extirpated from living animals without bad consequences.

Formation of the blood in the ovum.—In the incubated egg the sole material for the first formation of the blood, is the substance of the germ or germinal membrane, which itself grows by assimilation of the fluid of the egg, or the yolk. It may be distinctly observed, that the blood is generated in the germinal membrane before the vessels and glands are formed, which in the adult have some influence on the formation of the blood. The germinal membrane, at first simple, is after a short time found to consist of an upper, thinner, or serous layer, and an under, thicker, or mucous layer. Around the first trace of the embryo, which is visible in the centre of the germinal membrane, a transparent space, or *area pellucida*, is formed, while the part of the germinal membrane nearer the circumference remains opaque, and this opaque portion again is soon divided by a line of separation into an outer and inner space. These changes take place in the ova of birds, during the first sixteen or twenty hours.† That part of the opaque portion of the germinal membrane which is immediately within the line of separation above-mentioned, and which surrounds the innermost portion or transparent area, is called the *area vasculosa*, because within it the blood and vessels are formed. As far as the *area vasculosa* extends there is found between the two layers of the germinal membrane a granular deposit, which soon becomes arranged in dense granular islets, separated by transparent interspaces; and in these interspaces first a yellowish, afterwards a red fluid,—the blood,—collects. The presence of blood is first distinctly observable in the periphery of the *area vasculosa*.

In the bird, the red particles of the blood for the first few days after its appearance in the germinal membrane, are, according to Prevost and Dumas, round, and do not begin to assume the elliptic form before the sixth day; on the ninth day they are all elliptic.‡ Hewson, Schmidt,§ and Doellinger, have made a similar observation.

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* Structur und Wachsthum der Thiere und Pflanzen, p. 86.

† Von Baer; de ovi Mammalium genesi.

‡ Froriep, Notiz. 175.

§ Uber die Blutkörner. Würzburg, 1822.

The same fact has been observed also by Baumgärtner[*] in reptiles and fishes, and by E. H. Weber[†] in the tadpole.

Baumgärtner describes the formation of the red particles of the blood in the following manner:—The corpuscules, he says, are at first not elliptic or flattened, but globules composed of a number of smaller globules similar to those of the yolk of the egg; they gradually become transparent, and at the same time this granular state disappears; the transparent ring is then developed, and the nucleus formed. The elliptic form is gradually assumed. Weber also describes the corpuscules of the blood in very young tadpoles to be composed of several smaller granules. Baumgärtner supposes that the smaller granules here mentioned are derived from the yolk. Another mode in which Doellinger[‡] and Baumgärtner imagine the red particles of the blood to be formed, both in young and adult animals, is the separation of particles from the parenchyma. According to Schultz,[§] the blood-corpuscules are formed in the germinal membrane of the chick, by the development of a delicate membranous vesicle around a globule of the yolk, and by the subsequent extension and flattening of this vesicle.

It is evident that in the embryo the blood is formed from the substance of the germinal membrane, which assimilates to itself the fluids of the egg, and that no particular organ is then required; for at that period no organs, such as intestinal canal, liver, spleen, or lungs, exist. This fact teaches us that we must not expect to discover the process of the formation of the blood and its red particles (from the globules of the chyle?) in any special organs of the adult animal; indeed, it is very probable that in the adult the chyle is converted into blood under the influence of the same general vital conditions which are in action in the incubated egg.

Action of respiration in the production of blood.—Respiration seems to have an essential share in the process, inasmuch as even in the incubated egg the influence of atmospheric air, and in aquatic animals that of water containing air, seems to be quite necessary for the development of the embryo, and the air in these cases suffers the changes which ordinarily take place in respiration. In the fœtus of mammalia there is, however, even at a later period, no distinct difference between arterial and venous blood, and the want of respiration is supplied by a process of another kind, which is maintained by means of the union of the ovum with the uterus, but of which the nature is unknown.

Perhaps respiration is not more immediately necessary for the formation of the colouring matter than for the maintenance of life. That the blood during respiration undergoes a change necessary to the preservation of life, is proved by death occurring whenever this function is interrupted. The nature of the change, however,—the influence which respiration has on the formation of the blood,—cannot be accurately determined; we have no means of ascertaining whether the blood would acquire its red colour and the other properties connected with this colour,—whether any red particles would be developed,—if respiration were not performed. A very small portion only of the changes which take place in the passage of the blood through the lungs is recognisable, and that is the change of the dark red colour of the blood to a bright red, which during its passage through the capillary vessels of the body generally is reconverted to a dark red. But unfortunately even here it is the change of colour only that we are acquainted with, and not the chemical change which accompanies it.

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[*] Uber die Nerven und Das Blut. Freiburg, 1830.
[†] Loc. cit. iv. 478.
[‡] Denkschr. der Acad. zu München, vii. 169.
[§] System der Circulation. Stuttgart, 1836.

The absorption of oxygen and the separation of carbonic acid are the causes to which arterial blood owes its property of being the sole stimulus of living structures. Venous blood which has not undergone this change has a poisonous action on the organs of the body, particularly on the nervous system, and annihilates their irritability; its action being similar to that of carbonic acid, sulphuretted hydrogen, carburetted hydrogen, and some other gases, by which the irritability of the organs of the body is destroyed, and by most of which the arterial blood is darkened in colour. Cuvier* supposes, indeed, that the arterial quality of the blood is diminished even during its course from the heart to the capillary vessels, by reason of some change of composition which it undergoes, and thus explains the inferior degree of vitality possessed by parts distant from the heart.

Another difficulty which we are quite unable to solve is, whether the venous blood is incapable of supporting life from having lost something which arterial blood possesses, or from having suffered some noxious change in the combination of its elements, the natural combination being in the latter case again restored by respiration and the separation of the carbonic acid. It is very remarkable, however, that the venous blood of the embryo of mammalia, which, strictly speaking, does not respire, has not this poisonous influence; whether it is that the injurious quality cannot be developed until respiration, and the consequent reciprocal action of true arterial blood with the tissues take place, or that the want of respiration is supplied by the connection of the embryo with the mother.

Since the blood is constantly throwing off carbon in the process of respiration, it might be thought that the relative proportion of nitrogen in the body ought to increase. But this increase is not permanent; for an excess of that element is being constantly excreted from the body in the urea and uric acid of the urine, which are more highly azotised than any animal substance.

The influence of the spleen, supra-renal capsules, and of the thyroid and thymus glands on the formation of the blood, is not at all understood.

Influence of the excretions on the formation of the blood.—The separation from the blood of certain matters which are afterwards eliminated from the animal economy, has a great share in preserving the normal composition of the circulating fluid. Some of the matters here alluded to have been introduced from without, and are either in themselves useless, or are in too abundant quantity. Of these, water is got rid of by exhalation from the lungs and skin and by the urine; the mineral substances are expelled chiefly by the urine; and matters containing an excess of carbon, nitrogen, oxygen, or hydrogen, are eliminated in various ways:—the carbon by the lungs; combinations containing much carbon and hydrogen by the liver; and those in which the nitrogen is abundant by the kidneys. Some substances, also, that are newly formed in the body, being taken up into the blood, disturb its normal constitution, and must therefore be excreted from it. Such seem to be several of the matters contained in the urine. This shows how the proper composition of the blood when once established is maintained.

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* Verg. Anat. p. 147. Anatomie comparée.

Another question is, whether the separation of certain ingredients from the new nutritive matter which the blood derives from the food, contributes essentially to the original production of the normal composition of the blood. The lithic acid of the urine, which resembles urea in containing a greater proportion of nitrogen than any other organic substances,* is derived without doubt, at least in part, from this source; for its quantity in the urine is increased by merely taking animal food, or substances containing a large proportion of nitrogen; and in the urine of herbivorous Mammalia it does not exist, being replaced by hippuric (urino-benzoic) acid. It is not yet known whether lithic acid pre-exists in the blood, and is merely separated from it by the kidneys, or whether it is first formed in the urinary organs; although under certain circumstances it is deposited from the blood in different parts, for instance, in the neighbourhood of joints, forming gouty concretions.

Urea is not formed originally by the organs which excrete it,—namely, the kidneys; for Prevost, Dumas, Mayer,† Vauquelin and Segalas‡ have shown that it can be detected in the blood when the kidneys have been extirpated, so that the cause of its not being found in healthy blood§ appears to be its excretion by the kidneys as fast as it is formed. On the third day after the extirpation of both kidneys, the following symptoms arise:—Brown, copious, very fluid evacuations from the intestines; vomiting, and fever, with the temperature elevated to 110° Fahr., sometimes, however, depressed to

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* For the composition of urea and uric or lithic acid, see the Section on Secretion, chapter viii.

† Tiedemann u Treviranus, Zeitschrift für Physiol. 2, 2, 278.

‡ Biblioth. Univers. xviii. 208.—Meckel's Archiv. viii. 325.

§ Dr. Marchand has found that the solution of the alcoholic extract of serum of cow's blood when mixed with chloride of sodium, causes that salt to crystallise in octahedrons instead of cubes. And since the property of thus modifying the form of crystallisation of common salt is, as far as we at present know, possessed by urea alone, he regards this fact as a nearly positive proof of the presence of that substance in healthy blood. When the kidneys are affected with Bright's disease, the urea is excreted in diminished quantity, and is then always present in the blood (Christison), and in the dropsical effusions (Rayer and Marchand).

92° Fahr.; a small and quick pulse, rising to 200 beats in a minute; and frequent, short, and at last laboured breathing. Death ensues between the fifth and the ninth day. By some writers urea in the blood is supposed to be a useless compound, which has entered the circulation with the more necessary products of the conversion of food into blood; and, in support of this view, they cite the varying proportion of urea with the quality and quantity of animal food found in the urine as the product of renal secretion from the blood. By others, urea is believed to be an effete product of the change of material constantly taking place in the organised parts of the body. The formation of urea by reptiles, which have fasted for months, and its presence in the urine of a madman who fasted eighteen days, and in the urine of herbivorous animals whose food contains very little nitrogen, and also in that of the carnivorous, as the dog, when fed for eight days on a diet of sugar perfectly free from nitrogen, favour this last opinion. It is the more probable one, from the circumstance, also, that the lithic acid at least is formed in the embryo. It is found in the allantois not only of birds, but also of Mammalia; and the fœtus of Mammalia, while in the uterus, does not respire in the proper sense of the word, and therefore has no arterial blood, although the want of respiration is supplied by its connection with the mother. Besides, the formation of the substances of which we are here speaking, commences extremely early in the embryo.

By means of the skin the blood throws off lactic acid, lactate of ammonia, muriate of ammonia, and carbonic acid. Lactic acid, which also passes off by the urine, is, according to Berzelius, an universal product of the spontaneous decomposition of animal matters within the living body; it is formed in great quantity in the muscles, is neutralised by the blood and its alkali, and separated in the kidneys with acid urine.

The important office which the bile performs in the assimilation of animal matters in the intestines is not well understood. The fact of its being poured, both in vertebrata and in mollusca, into that part of the canal where the formation of the chyme is completed, proves that it is not excrementitial merely; besides its most abundant component, picromel, has evidently some connection with the assimilation of the chyme, for it is not found in the fæces. Some, however, of the components of the bile are certainly excrementitious matters thrown off from the blood; and these are essential components of the fæcal matter. Such are the cholesterine and resin of the bile, and the colouring matter, of which no traces are found in the chyle. The liver, therefore, frees the blood from an excess of matters containing carbon and hydrogen, and from fatty matter, while the kidneys remove from it the superabundance of those materials which contain a large proportion of nitrogen. The colouring matter of the bile, which is excrementitious, also contains nitrogen. The lungs and liver are so far analogous, inasmuch as both separate from the blood substances containing a large proportion of carbon. In the former case, however, it is already combined with oxygen; in the latter case, it is still in the oxidisable state. Earlier physiologists, and more recently Autenrieth, and particularly Tiedemann and Gmelin, have directed attention to a certain vicarious action in the functions of the lungs and liver; and although it does not appear that the size of the liver is throughout the animal kingdom in the inverse ratio of the size of the respiratory organs, yet pathological observations are certainly in favour of the existence of such a relation.

The excretory action of the liver is exerted also under circumstances in which digestion is not carried on. For although the liquor amnios is swallowed by the fœtus, it is only during the latter period of gestation; while the liver is developed and secretes at a very early stage of fœtal life, and the bile, although less bitter and less coloured at that period, contains, according to Lassaigne,* a green resinous matter and a yellow colouring matter, but no picromel. In fact, it is the excrementitious matter of the bile of the fœtus, which collects together with intestinal mucus in the lower part of the canal, forming the meconium. It appears from the experiments of Tiedemann and Gmelin, that the secretion of bile is still carried on in hybernating animals during their state of torpor. These inquirers also adduce the observation of Cuvier, that in many molluscous animals a small portion only of the bile is poured into the upper part of the intestinal canal; while the rest is evacuated by a separate duct either into the cæcum, as in the Aplysia, or near the anus, as in the Doris and Tethys. It is, however, at present, very doubtful whether the secretion which in the last two animals is poured out near the anus, is bile, and it certainly cannot be the greater part of it. I have examined several large examples of the Doris, and found the excretory duct which Cuvier discovered. It appears, however, to arise, not like the bile ducts, from the clustered vesicles of the liver; but by numerous branches, some of which run between the lobes of the liver, from a reticular tissue which is extended over its whole surface, while one large trunk comes from the interior. To me it appeared that two kinds of fluids are here separated from the blood, which is distributed through the mass of the liver, there being, perhaps, a special apparatus for the formation of each secretion. In its point of termination, the duct discovered by Cuvier is analogous to the excretory duct of the saccus calcareus of snails, but its origin is certainly very different.

The frequency of diseases of the liver and the intestinal canal in tropical climates and hot seasons, and of affections of the liver and abdominal organs in damp marshy air, is still unexplained. Could it be ascertained that these circumstances in some way impede the circulation and cause congestions, it would be easy to conceive why the liver and intestinal canal should suffer most in consequence; for the circulation in these viscera must be doubly impeded, the blood of the intestinal veins and vena portæ having to circulate through a second capillary system, namely that of the liver, before it reaches the general circulation. Tiedemann and Gmelin maintain that the increased secretion of bile in tropical climates is required to compensate for the diminished purification of the blood in the lungs; many persons supposing that the function of the latter organs is rendered inefficient on account of the rarification of the air by the heat. Stevens* thinks this assumption incorrect; for in the West Indies, he says, the inhabitants of the smallest islands, which are the driest and hottest, but in which there are no stagnant waters, are not subject to diseases of the liver, and increased secretion of bile, and these diseases are prevalent in hot climates only where the atmosphere is impregnated with malaria.

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* Ann. de Chim. et de Phys. xvii. 304.

SECTION II.

OF THE CIRCULATION OF THE BLOOD AND OF THE VASCULAR SYSTEM.

CHAPTER I.

Of the Forms of the Vascular System in the animal kingdom.

Peculiar chemical changes of an organic nature are effected in the blood in special organs of the body. All parts of the system, however, require a supply of blood which has undergone these changes, and hence the circulation of this fluid is indispensable.

The circulation of the blood was discovered in the higher animals by Harvey in 1619. It has since been found to have a much more extended existence; and although it cannot be asserted to be a universal character of all animals, yet at every advance of observation new traces of vessels are discovered in the most simple beings. Ehrenberg has described them in the rototoria, and even microscopic minuteness does not appear to preclude the existence of this complex structure. The following are the more important facts relative to the different forms of the vascular system in the animal series:—

Circular currents in the lower animals.—In several of the lowest tribes of animals there are small circular currents of granules similar to those in the Chara. These circular currents in animals appear not to be dependent on the action of a heart, but have been supposed to be the result of ciliary motion, although neither Dutrochet, Donné, nor any other observer, has been able to detect cilia on the globules lining the cells, in which the rotation of granules is observed. (See the Bibliotheque Univers. Jan. 1838; and Comptes Rendus, 1838, Nos. 16 and 18.)

In the lowest animals of which the circulation has been accurately observed, as in the Planariæ, Echinodermata, and leech tribe, the motion of the blood is effected by one, two, or more contractile vessels. These vascular trunks are, however, neither arteries nor veins, but are in part contractile hearts, which force the blood into anastomosing branches.

Holothuria.—The vascular system in the Holothuria, the discovery of which is attributed to Tiedemann, but was previously described and beautifully figured by Hunter,[*] seems to be of this nature: it is situated, in common, on the intestine and on the respiratory organ, and is independent of the system of water tubes with which the skin of this animal is provided for the erection of its tentacula.[†]

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* Observations on the Healthy and Diseased Properties of the Blood, London, 1832, p. 59.

In the Annelida there is a progressive contraction of the vascular trunks, advancing regularly in one direction, and thus, according to Dugés, driving the blood in a continued circle in the larger vessels; while at the same time the circulating fluid is thrown alternately from side to side through the transverse anastomising branches, one trunk being filled while the other contracts, as is seen in the Hirudo vulgaris.[‡] M. Milne Edwards,[§] who has recently investigated very accurately the circulating system of the marine Annelida, finds that while they all agree in having two principal systems of vessels, the dorsal, in which the direction of the current is forwards, and the ventral, in which it is from before backwards, the contractile organs which give rise to this motion of the blood are in different genera situated at different parts of the circle. In the Terebellæ the anterior part of the dorsal vessel acts the part of a pulmonic heart, and drives the blood into the branchiæ, which are themselves contractile, and force the blood into the ventral vessel, or systemic aorta. In the Nereides the dorsal vessel acts the part of the systemic heart.

Insects.—In animals in which there is but one contractile vessel, the circulation is simple but perfect; the fluctuating motion of the blood from side to side does not exist, and there are distinct arterial and venous currents. Such is the circulation which Carus[||] has discovered in insects: the blood flows in a simple circle; being impelled forwards by the dorsal vessel, it returns in the opposite direction through the body, and again enters the dorsal vessel.

The currents are very simple and do not ramify; the feet, for example, have each two currents running in opposite directions, the arterial being reflected uninterruptedly into the venous, so as to form a loop. It is at present unknown whether the internal organs of insects receive any separate vascular currents.

Arachnida and Crustacea.—The circulation in the Arachnida and the lower Crustacea, such as the Daphniæ and Onisci, according to Zenker and Gruithusen, is nearly as simple as in insects. There is no distinct pulmonary circulation; but a part of the blood is aerated in the respiratory organs in its course through the general circulation. In the Arachnida with tracheal organs of respiration as well as in insects, the blood is aerated by the tracheæ which ramify most minutely in all parts of the body.

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[*] See the Catalogue of the Mus. of the College of Surgeons, vol. i. p. 251.

[†] Tiedemann, Anatomie der Röhrenholothurie, &c.

[‡] J. Müller, Meckel's Archiv. 1828; and my observations on the Arenicolæ in the 4th vol. of Burdach's Physiol. On the subject of the annelides generally, consult Dugés, Ann. des sc. nat. t. xv.

[§] Annal. des sc. nat. 1838, t. x.

[||] Entdeckung eines Blutkrieslauf, &c. Leipzic, 1827.—Nov. act. nat. cur. t. xv. p. 2. The visible circulation of the blood in insects was imperfectly known to Leeuwenhock (Arcana Naturæ) and Baker. Hunter was well acquainted with the heart or dorsal vessel of insects, and also with the lateral canals, which he correctly regarded as veins,—and he knew the course of the circulation from dissection and injections. (See vol. iii. of Mr. Palmer's Edition of Hunter's Works, p. 173; and the Catalogue of the Hunterian Museum, vol. ii. p. 31.)

In the higher Crustacea there is either a long tubular heart, as in the Squillæ and allied genera, or a short wide one, as in the Decapoda. The blood is collected from the body by veins, and by them carried to the branchiæ; from the branchiæ it returns to the heart, which again distributes it to the body. That this is the course of the blood in Crustacea was discovered by MM. Edwards and Audoin, and while at Paris I satisfied myself of it by injecting a lobster. I agree with Meckel that Strauss is incorrect in considering the membranous covering of the heart of these animals to be an auricle.*

Mollusca.—The circulation in the Mollusca is similar to that in the crustacea. In the naked *Acephala or Tunicata,*—as the ascidia and salpa,—the veins from the branchiæ enter the ventricle immediately. In the *Conchifera,* as well as in most *Gasteropoda,* the blood is first collected in an auricle (in the conchifera there are two auricles), and thence passes to the ventricle.

In the majority of the Mollusca all the venous blood circulates through the branchiæ before reaching the heart. In Gasteropoda (Lima and Helix) the blood from the lungs is in part distributed to the organ which secretes the lithic acid (*saccus calcareus*), and is then collected again to be sent to the auricle.

Cephalopoda.—In the Sepia there are three separate ventricles. The systemic ventricle or heart gives off the aorta, which distributes the blood to the body, whence it is brought by veins to the two lateral branchial hearts; by these it is sent to the branchiæ, and by the branchial veins is returned to the systemic heart.

In *Fishes* there is but one auricle and one ventricle, the venous blood from the body generally being collected in the auricle, and thence transmitted to the ventricle. By the ventricle the blood is impelled through the contractile *bulbus arteriosus* into the branchial arteries, generally four in number on each side, being by them conveyed to the branchiæ, from which it is returned by the same number of branchial veins; these branchial veins unite to form the aorta, by the branches of which the blood is distributed to the body.

In *Reptiles* there are two auricles and one ventricle imperfectly divided into two cavities. The venous blood brought from the body to the right auricle is partially mixed in the ventricle with arterialised blood, which is received from the lungs by the left auricle, and poured into the ventricle: from the right compartment of the ventricle the left aortic trunk and the left pulmonary artery generally arise; from the left cavity the right aortic trunk and generally the right pulmonary artery; it is from the right aortic trunk that the arteries of the head and upper extremities arise, and these parts, as in the fœtus of mammalia and birds, receive a larger proportion of arterial blood: the two aortic trunks unite behind to form the descending aorta.

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* See Ann. d. sc. nat. 1827, tab. 24-32.

Amphibia.—Intermediate in the chain of animals between fishes and reptiles is the class of Amphibia or batrachian reptiles, of great interest in a physiological point of view, on account of the metamorphosis of the branchial into the pulmonary circulation which is observed in them. All the Amphibia* have two auricles, the separation between which is not visible externally, and one ventricle.†

In the Frog.—The branchial circulation in the frog, during the earliest period of its larval condition, when it has external branchiæ, is similar to that in the larva of the salamander. During the second period, in which it has internal covered branchiæ, and in which the lungs begin to be developed, the distribution of the vessels is, according to Huschke, more like that of fishes; the arterial trunk divides into the branchial arteries for the four branchial arches, and the branchial veins collecting into large trunks run parallel to the arteries. In the larva of the frog, however, there is a short anastomosing branch connecting the artery and vein at the commencement of each branchial arch, which does not exist in the fish. After the metamorphosis there remains on each side but one arterial arch, which, after giving off behind the arteria brachialis, unites with that of the opposite side to form the aorta abdominalis. The pulmonary arteries and those of the head, although they appear to arise from the commencement of these two aortic arches, do not really communicate with them; for, when accurately examined, each of the two diverging stems into which the *bulbus arteriosus* divides, is found to consist of three tubes united apparently into one trunk, but internally separated by thin septa. These tubes are the remains of the branchial arteries; the middle one is continuous with the aorta; the most inferior gives off the pulmonary artery and a vessel to the occiput, while the superior one forms the arterial trunk from which the head is supplied. Near the origin of the arteries of the head there is a glandular enlargement, —the so-called carotid gland, which Huschke has shown to be formed of minute ramifications of the artery which enters it, and of the venous radicles, which again unite into a single trunk that issues from the mass. This body is supposed to be the remains of the capillary vessels of the first branchial arch. I have satisfied myself that it has a cavity in its interior, and that the stem entering it is continuous till its exit, passing through a spongy tissue, which is most dense externally, although the external surface when finely injected does present, as Huschke describes, a delicate network, formed from vessels passing in and out.

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* On the heart of the amphibia, consult Weber's Beiträge zur Anat. und Physiol. Bonn, 1832. The existence of two auricles in the perreni-branchiate amphibia was discovered by Mr. Owen, (see Transactions of the Zoological Society for 1834,) and a year later by Prof. Mayer of Bonn, (see his Analect. zur vergl. Anat. 1835.)

† For an account of the characters which distinguish amphibia from reptiles, see J. Müller, in Tiedemann's Zeitschrift, iv. 2.

Aortic arches in the embryo of the higher Vertebrata.—The true Reptiles never possess branchiæ, and they undergo metamorphosis only during the fœtal state, like the other Vertebrata. In the earliest period of fœtal life, the embryos of all vertebrate animals have clefts in the neck, and between them, arched plates. In these plates run the aortic arches, which unite again posteriorly into one common trunk. This was discovered by Rathke; it is satisfactorily seen in the embryo of the bird on the third day of incubation. A similar structure, but less distinct, exists also in Mammalia and in man. It is more easily seen in the embryo of Reptiles. In these higher Vertebrata, however, there are no real branchiæ with branchial lamellæ, but merely branchial arches, from which in Fishes and Amphibia the branchia are developed by ramification of the aortic arches, while in all other vertebrate classes they gradually disappear; being, it would seem, converted into the cornua of the os hyoides.* In all vertebrate animals, then, during the earliest stage of existence, the main arterial stem divides into aortic arches. These arches are indeed persistent in reptiles; in some cases two on each side,—as in the true lizards and blind worms;—in other cases one only on each side,—as in serpents. In the higher vertebrata,—birds and mammalia, which have two auricles and two ventricles,—it is during the fœtal state only that the several aortic arches exist; at first, indeed, several on each side, which unite posteriorly to form thè descending aorta. In mammalia there are during fœtal life two aortic arches, which unite posteriorly to form the descending aorta. Of these, one arises from the left ventricle, and gives off the arteries for the upper part of the body; the other from the right ventricle gives off the pulmonary arteries as lateral branches. The continuation of this latter arch, namely, the *ductus arteriosus*, by which it unites with the aortic arch, at last ceases to be pervious, and then the pulmonary arteries become the sole branches of the trunk arising from the right ventricle. The arch of the aorta, or *arcus ventriculi sinistri*, in mammalia, turns from the left side behind the œsophagus, while in birds it turns from the right side; but when it is recollected that in the embryo state of both classes of animals there are several arterial arches on each side, this apparent anomaly becomes easily intelligible. Besides the communication between the two arterial arches, there is in the fœtus another means of communication between the two sides of the heart, namely, the *foramen ovale*. When either this opening, or the *ductus arteriosus* remains unclosed after birth, the arterial and venous bloods are mixed, and the cœrulean disease is produced.

Varieties in the circulation dependent on the relation between the less and greater circulations.—As soon as a true circulation is met with in ascending the animal scale, all further modifications depend on the relation in which the vessels of the respiratory organs, or the smaller circulation, stand to the vessels of the body, or the greater circulation. Thus either a portion only of the blood is aerated in the course of the greater or systematic circulation, in which case the smaller or pulmonary circulation, to use Cuvier's expression, is merely a fraction of the greater, or all the blood must first pass through the smaller circulation of the lungs or branchia, before it is distributed to the body generally.

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* J. Müller, Meckel's Archiv. 1830, p. 419.

The varieties which nature presents in the origin of the arteries and veins of the respiratory organs from the systemic circulation are very numerous, and seem, indeed, to comprehend all imaginable forms. They may be arranged as follows:—

1. The smaller circulation a fraction of the greater circulation.
2. The smaller circulation opposed to, or distinct from, the greater circulation.

Portal circulation.—Besides the pulmonary circulation, there is in all vertebrate animals another still smaller circulation, which, like the branchial circulation of amphibia, is an appendage merely of the general circulation. This is the portal circulation; it is a mere subordinate part of the venous circulation, in which the blood makes an additional circuit before it joins the rest of the venous blood. There are in the vertebrate classes two portal circulations; one of the liver, the other of the kidneys. The latter exists only in reptiles, amphibia and fishes; the former in all the vertebrata.

In Mammalia, including man, the veins which collect the blood from the spleen, stomach, intestines, gall-bladder, and pancreas, unite to form the portal vein, which ramifies through the liver like an artery; from the capillary vessels of the liver, the blood, a part of which was supplied by the hepatic artery, returns through the hepatic veins to the vena cava, and there becomes mingled with the venous blood of other parts. In the other classes of the vertebrata, a part of the blood of the lower extremities also is carried to the portal vein; and in fishes sometimes the blood from the air-bladder and genital organs.*

In reptiles and amphibia, the kidneys have, beside the renal arteries, portal veins, which bring to them a part of the blood of the posterior extremities and tail. The blood returned from the posterior extremities, from the abdominal muscles, and from the tail, goes partly to the liver, and partly to the kidneys:—in frogs and salamanders to these viscera only; while in some reptiles, as the crocodile, a portion of it is sent to the vena cava. In some fishes, as for example, the gadus, the blood of the tail and middle part of the body goes wholly to the kidneys; in others, as in the carp, pike, and perch, the venous blood of the posterior parts of the body is distributed to the kidneys, liver, and vena cava.†

Meckel, who considered these portal veins which carry blood to the kidneys, to be ordinary venous trunks conveying it from them, founded his opinion chiefly on the class of birds, in which Jacobson incorrectly described portal veins going to the kidneys; but the non-existence of these veins in birds, which had been previously proved by Nicolai, is no argument for their not existing in reptiles, amphibia, and fishes, in which classes indeed Nicolai has established their presence.

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* See Jacobson, Nicolai, and Rathke.

† Jacobson, Meckel's Archiv. 1817—147. Nicolai, Isis, 1826—404.

OF THE HEART.

Essential characters.—The principal impelling power of the circulation is the rhythmic motion of the heart. The heart is that part of the vascular system which, from having muscular parietes, not possessed by the blood-vessels generally, is endowed with contractility. In its simplest form, therefore, the heart still resembles a vessel; this is exemplified by the vessel-like multiple hearts which constitute at the same time the main vascular trunks of the annelida, by the contractile vascular trunks on the intestinal canal of the holothuria, and by the dorsal vessel of insects, which is divided into a series of chambers. The correctness of this view is very evident on examining the organ in different orders of the crustacea: thus, in the squillæ the heart is a contractile dorsal vessel, while in the decapoda it is a short and circumscribed chamber or ventricle.

In the embryo of the higher animals the heart is at first tubular, and is nothing more than the contractile part of the vessels at which the venous trunks are reflected into the arterial stem.

In the adult of the higher animals, too, the heart consists of a short double muscular sac; but the contractile substance is continued for a certain extent on the venous trunks that open into it, and in fishes and reptiles, upon a part of the arterial stem, the so-called *bulbus aortæ.* In the frog the trunks of the venæ cavæ can be most distinctly seen to contract regularly like the heart. This was observed by Haller,[*] Spallanzani, and Wedemeyer. The contractions appear to me to extend over the inferior cava as far as the liver; and are still continued and with regularity, in the venous stems, after the heart is removed. First, the cavæ contract, then the auricles, next the ventricles, and lastly the *bulbus aortæ.* I have observed contraction of the great veins in the mammalia, both in the young marten and in the young cat; in these animals, however, the contraction of the venæ cavæ and pulmonary veins is synchronous with the contraction of the auricles. In young animals the pulmonary veins, as far as they can be followed in the substance of the lungs, present most distinct contractions as long as their coats are not injured by pressure. The contraction of the cardiac end of the superior vena cava is as distinct. But, during the contraction, the distance to which the contractile substance of the cava extends may be clearly distinguished; beyond this limit the vessel exhibits not the slightest contraction, but becomes rather turgid and distended by blood at the time that the part contiguous to the right auricle is contracted. Retzius has described a layer of peculiar fibres at the origin of the vena cava of serpents, and E. H. Weber has found the same in the inferior cava of mammalia.

These observations indicate, that in its simplest form the heart is merely that part of the vascular system which is furnished with muscular structure, and endued with the power of active motion; and that it is still a heart when, as in the lower animals, it has the form of a simple contractile vascular stem. The rest of the vascular system consists merely of tubular canals, which in reference to motion are passive, but may exert other important influences on the blood. Thus, for example, by virtue of a power, the nature of which is not known, they maintain the fluidity of the blood as long as it is in motion; and the interchange of matters between the blood and the tissues which takes place through their parietes is effected by their influence.[*]

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[*] Elementa Physiol. t. i. 125.

CHAPTER II.

OF THE GENERAL PHENOMENA OF THE CIRCULATION.

Cardiac Beat and the Pulse.—The heart of an adult man in the middle period of life contracts from seventy to seventy-five times in a minute. The frequency of its action gradually diminishes from the commencement to the end of life, thus:—

In the embryo the number of beats in a minute is	150
Just after birth,	from 140 to 130
During the first year,	130 to 115
During the second year	115 to 100
During the third year	100 to 90
About the seventh year	90 to 85
About the fourteenth year	85 to 80
In the middle period of life	75 to 70
In old age	65 to 50

In persons of sanguine temperament the heart beats somewhat more frequently than in those of the phlegmatic; and in the female sex more frequently than in the male. The number of the pulsations in a minute varies very much in different animals.

In fishes the number of beats in a minute is	from 20 to 24
In the frog	about 60
In birds	from 100 to 140
In the rabbit	about 120
" cat	110
" dog	95
" sheep	75
" horse	40

After a meal the heart's action is accelerated, and still more so during bodily exertion; it is slower during sleep. The observations of Dr. Knox,[†] Nick,[‡] Hohl,[§] and Dr. Guy,[‖] have shown that, in the state of health, the pulse is most frequent in the morning, and becomes gradually slower as the day advances; and that this diminution of frequency is both more regular and more rapid in the evening than in the morning. It is found, also, that, as a general rule, the pulse is more frequent in the standing than in the sitting posture, and in this than in the recumbent position; the difference being greatest between the standing and the sitting posture. Thus, in 100 healthy males of the mean age of 27 years, and in a state of rest, Dr. Guy found the mean number of the pulse, standing, 79; sitting, 70; and lying, 67. The extremes were very far distant from this mean result. Exceptions to the general rule were met with in 34 cases out of the 100. In either sex the effect of change of posture is greater as the frequency of the pulse is greater, and in accordance with this, is more marked in the morning than in the evening. But it is remarkable that in the female the pulse, though more frequent, is much less influenced by posture than in the male. In early youth, also, the effect of posture on the pulse is less than in adult age, and this influence of age is greater in the female than in the male. Different causes have been supposed to account for the effect of posture on the frequency of the pulse. Dr. Guy, by supporting the body in different postures, without the aid of muscular effort of the individual, has proved that the increased frequency of the pulse in the sitting and standing positions is really dependent on the muscular exertion engaged in maintaining them; the usual effect of these postures on the pulse being almost entirely prevented when the ordinarily attendant muscular exertion was rendered unnecessary(*a*). The effect of food, like that of change of posture, is greater in the morning than in the evening.* According to Parrot,† the frequency of the pulse increases in a corresponding ratio with the elevation above the sea:—

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[*] I have given a more elaborate description of the various forms presented by the circulation in the animal kingdom, in Burdach's Physiologie, B. iv.

[†] Edinb. Med. Surg. Journal, 1815; and a more recent paper in the 11th vol. of the same journal.

[‡] Loc. citat.

[§] Die Geburtshülflicke Exploration. Halle, 1835.

[‖] Guy, Hospital Reports, Nos. vi. and vii.

When the pulse at the level of the sea was	70
At 1000 metres‡ above its level, it was	75
1500	82
2000	90
2500	95
3000	100
4000	110

In inflammations and fevers the pulse is much more frequent than during health. When the vital powers decline, it becomes frequent and feeble. In nervous affections with more oppression than exhaustion of the forces, the pulse is often remarkably slow.

If the heart of a living mammiferous animal or bird is laid bare, the two ventricles are seen to contract simultaneously, and the two auricles, with the commencement of the pulmonary veins and of the venæ cavæ, also simultaneously, the contraction of the auricles and

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(*a*) In hypertrophy of the heart, the *differential* pulse, as it is called, is not met with. There is no change in the pulse with change of posture.

* The greater number of the facts relative to the variations of the pulse under the influence of posture and period of the day, were first ascertained by Dr. Knox; they have been confirmed and others added by the numerous and well-conducted observations of Dr. Guy, (Med. Gazette, 1839.)

† Froriep, Notizen, 212. See also Nick, über die Bedingungen der Häufigkeit des Pulsus. Tübingen, 1826.

‡ A metre is about three feet three inches.

that of the ventricles not being synchronous. In warm-blooded animals the auricles contract immediately before the ventricle. In the frog the contractions of the venous trunks, of the auricles, the ventricle, and the *bulbus aortæ*, appeared to me to follow the order in which I have specified the parts, the intervals between the four contractions being nearly equal; so that the same interval of time elapsed from the contraction of the auricles to the contraction of the ventricle, as between the contraction of the ventricle and that of the bulb of the aorta. I am convinced, from repeated observations, that the auricles and ventricle do not, as Oesterreicher* asserts, alternate in action at equal intervals, like the motions of the pendulum, but that the time that intervenes between the contraction of the auricles and the contraction of the ventricle is much less than that which elapses from the moment of the contraction of the ventricle to the moment when the auricles again act; and that generally the contraction of the bulbus aortæ and venous trunks occur in the interval of time last indicated. In warm-blooded animals I have seen the contractions of the auricles cease altogether for some moments, which must have been caused by the injury inflicted in making the observation. Under ordinary circumstances, the auricular contraction was always a very quick motion immediately preceding the action of the ventricle, the interval of time from the contraction of the auricles to the contraction of the ventricle being certainly very much shorter than the period that elapsed between the contraction of the ventricles and that of the auricles.

The contraction (systole) alone of the heart is an active state; the dilatation (diastole) is the moment of repose, in which the fibres are relaxed, and in which the blood is poured from the contiguous veins into the cavities of the heart, to fill the vacuum consequent on the relaxation of its fibres: the valves of the heart being so arranged as to allow the influx of the blood from the veins. The dilatation of the heart was supposed by Bichât, and some other French physiologists, to be an active movement, but Oesterreicher† has by a very ingenious experiment refuted this supposition. He removed the heart of a frog from the body, and laid upon it a substance sufficiently heavy to press it flat, and yet so small as not to conceal the heart from view; he then observed that during the contraction of the heart the weight was raised, but that during its dilatation the heart remained flat. This experiment shows that the dilatation of the heart is not a muscular act; at the same time, however, it must be recollected that the walls of the heart during life cannot become so relaxed at the time of the diastole, as in a heart removed from the body, even although the cavities of the heart were not filled with blood; for, in the living state, the capillary vessels of its substance are at the time of relaxation injected with blood, which, during the contraction, is pressed out of them, and this filling of its vessels must give it some degree of firmness and rigidity.

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* Lehre vom Kreislauf des Blutes. Nürnb. 1826.

† Loc. cit. p. 33.

The contraction of the ventricles of the heart would drive the blood into the auricles and veins, as well as into the arteries, if the valves were not so constructed and attached as to allow the expulsion of the blood only in certain directions. There are, it is true, no valves to prevent the auricles from forcing the blood into the veins; but the stream of venous blood towards the heart checks its regurgitation in this direction, while its passage from the auricle into the ventricle is free; for the valve at the auriculo-ventricular orifice is so attached as to allow the blood to flow into the ventricle, and yet, to prevent the regurgitation of the blood into the auricle, when the ventricle contracts; it being then, by the pressure of the blood itself, spread out so as to close the orifice. The escape of the blood from the ventricle into the great arteries is unimpeded, the pouch-shaped semilunar valves situated at the arterial orifice of the ventricle being separated from each other, and laid close to the walls of the artery by the stream of blood forced into it. And when the contraction of the ventricle ceases, regurgitation from the arteries cannot take place; for the blood itself presses down the valves towards the centre of the vessel, and spreads them out so as to close the orifice. The heart by this arrangement of its valves is constituted a kind of forcing-pump, like the common syringe with two valves, of which one admits the fluid on raising the piston, but is closed again when the piston is forced down, while the other opens for the escape of the water, but closes when the piston is raised so as to prevent the regurgitation of the fluid already forced through it.

The vascular system must be regarded as constantly filled with blood in all parts. The heart's cavities alone contract at each beat so as to expel nearly all their contents; but several observations show that even the ventricles do not empty themselves completely during their contraction. While the vessels, from the commencement of the arteries to the capillary vessels, and thence to the insertion of the venous trunks into the heart, are filled with blood, both during the contraction of the ventricles and at the time of their relaxation; neither air nor a vacuum exists in any part of the vascular system. So that the contraction of the aortic or left ventricle cannot advance the blood in the arteries except by forcing on the column of blood already contained in them; and the advance of the column is proportionate to the space which the quantity of blood forced through the aortic orifice by each contraction of the ventricle—namely, from one to two ounces—occupies in the commencement of the aorta. When the contraction of the ventricle remits, the cause of the motion ceases, but the elasticity of the arteries overcomes the resistance offered by friction in the minute vessels, and still forces the blood onwards; a continuous current is thus produced from the aortic valves to the capillary vessels. When the aortic ventricle again contracts, and again forces one or two ounces of blood into the aorta, the current is accelerated, and the column of blood is advanced to the same extent as before. The result of this succession of actions must be, that exactly the same quantity of blood enters the heart from the veins as was expelled from it in the same space of time by the contraction of the ventricles; for the whole mass of blood forms one great circle from the heart to the heart again—a circle, at each and every point of which the same quantity of blood must pass within a given time. The contraction of the ventricles would give rise to a vacuum within them, were it not that as soon as the contraction ceases, the blood impelled by the *vis à tergo* immediately flows from the veins and auricles into the ventricles to fill the impending vacuum; and it is the same with the auricles.

The pressure of the column of blood against the elastic walls of the arteries at every contraction of the ventricle, produces what is called the pulse. This phenomenon will be more particularly considered at a future page; here it is only necessary to remark, that the sensible pulse of the arteries is synchronous, or nearly so, with the contraction of the ventricle; it is somewhat later than the heart's beat, but the difference of time is scarcely perceptible. In the capillaries and veins the pulse is no longer perceived.

The impulse of the heart—pulsus cordis—must not be confounded with the arterial pulse. The heart's impulse is the shock communicated by the apex of the heart to the walls of the thorax in the neighbourhood of the fifth and sixth ribs.

Sounds of the heart.—When the ear, or a stethoscope, is placed over the precordial region, two sounds are heard following each other quickly at every beat of the heart. I have sometimes heard them in my own person at night when lying on the left side. Like the heart's impulse, these sounds are followed by a pause. The interval of time between the two sounds compared with the pause is, according to my observation, in the proportion of 1 to 3, or about $\frac{1}{4}$th of the time occupied by a single beat of the heart and the pause following it,—that is, about $\frac{1}{5}$th of a second. From repeated and long-continued observations I am satisfied that the first sound is synchronous with the impulse at the chest, and nearly synchronous also with the pulse of the facial artery, which is only $\frac{1}{50}$th of a second later than the impulse at the chest. The extent to which the first sound was distinctly heard in a healthy female did not exceed the space in which the impulse was felt; but the second sound was audible in nearly the whole extent of the chest, as high as the clavicles. In a pregnant woman the two sounds of the fœtal heart are heard through the abdominal parietes.

It is now pretty generally conceded that the first sound is due to the contraction of the venticles alone, as a muscular sound, and the second sound produced by the reaction of the columns of blood in the aorta and pulmonary artery upon the semilunar valves, spreading them out. Yet they must be rendered more perceptible by the heart coming into contact with the thoracic parietes during the systole by its apex, and during the diastole by its anterior surface.

We now pass to the description of the *greater and smaller circulation*. The *greater* circulation is the course of the blood from the left side of the heart through the arteries of the body, and back again through the veins to the right side of the heart. The course of the blood from the right side of the heart through the pulmonary arteries to the lungs, and back to the left side of the heart through the pulmonary veins, is called the *smaller* circulation. The blood, therefore, in fact, makes but one circuit, of which there are two divisions; in each of these the blood passes through capillary vessels from arteries to veins.

a. Smaller or Pulmonary Circulation.

The same quantity of blood enters the right auricle from the superior and inferior cavæ, and from the great coronary veins, as is impelled during the same period of time by the left ventricle through the arteries of the body. On the contraction of the auricle, the entrance of the blood of the veins is suddenly interrupted; but, when the auricle becomes relaxed, the blood rushes into it, and into the right ventricle also as soon as its contraction ceases. The auricle now contracts, and immediately afterwards the ventricle.* By the contraction of the auricle the blood is forced through that orifice, which remains free. It cannot regurgitate into the venæ cavæ, because it is in them opposed by the stream of venous blood which continues to be impelled towards the heart by the *vis à tergo;* and the opening of the coronary veins is closed, its valve being applied to it by the pressure of the blood in the auricle. The blood flows, therefore, into the right ventricle, which during the contraction of the auricle had become partially dilated and is now completely distended. While the right auricle is again dilating to receive the blood of the veins, the right ventricle contracts; and the blood, which cannot regurgitate into the auricle on account of the tricuspid valve being spread out by the pressure of the blood so as to close the auriculo-ventricular orifice, is driven into the pulmonary artery.

In this manner the venous blood returning from the body is, by the agency of the right side of the heart, transmitted to the pulmonary circulation. All the blood contained in the auricle is not, however, forced by its contraction into the ventricle. A portion regurgitates into the superior and inferior venæ cavæ; or, at any rate, the contraction of the auricle checks the flow of blood from the venous trunks towards the heart, which otherwise would continue uninterruptedly. When animals are opened during life, the great veins are seen to become turgid at the time of each contraction of the auricle; and in the larva of the triton I have seen the blood, in the inferior cava and hepatic veins, advance only in periodical jerks. When the escape of the blood from the ventricle into the pulmonary artery is impeded from any cause—whether organic change in the pulmonary artery, ossification of the semilunar valves, or impediment to the motion of the blood in the lungs—the regurgitation into the veins is necessarily increased. The regurgitation, or rather, periodic arrest of the blood in the great venous trunks, is called the pulsus venosus. It cannot extend far, on account of the yielding nature of the vein;

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* In vivisections I have frequently seen two contractions of the auricle for one of the ventricle, and sometimes the auricle did not contract at all. Both these circumstances were, however, most probably, anomalies.

that portion only of the venous system which is near the heart is affected by it.

The blood, once in the arteria pulmonalis, cannot return when the ventricle becomes relaxed; because the column of blood in the artery itself spreads out the semilunar valves at the mouth of the artery and closes it. The course of the blood from the right ventricle, through the lungs, to the left side of the heart, is called the smaller circulation; it does not really form a circle, for the blood does not return to the point from which it started. It is only a part of the course of the whole circulation, and would be better named the pulmonic course of the blood, in opposition to the systemic course of the blood, which together with it forms an entire circuit or circulation. In the pulmonic course, the venous blood expelled from the right ventricle by successive new portions of blood, flows from the branches of the pulmonary artery into the capillary vessels of the lungs, and through these capillary vessels,—in which it becomes scarlet, or arterial,—into pulmonary veins, which pour it into the left auricle. The capillary vessels in the lungs are, as in other parts, the network of minute vessels, which intervene between the smallest branches of the arteries and the radicals of the veins; but here the meshes of the network are extraordinarily small. The innumerable capillaries of the lungs are enclosed and spread out in the delicate membrane forming the cells in which the last branches of the bronchi terminate. This membrane that forms the pulmonary cells is a continuation of the mucous membrane of the trachea, and is, consequently, continuous throughout the lungs. The interior of the lungs, therefore,—omitting from consideration the bronchial tubes, arteries and veins,—may be regarded as a most extensive surface realised in a small space by the folding of a membrane in the form of cells, this membrane containing a dense network of capillary vessels. The process of respiration is effected by the contact of the air, which enters by the bronchi, with the inner surface of these cells, in the parietes of which the particles of blood circulate in most minute currents.

In the simpler animals, as in the amphibia, the lungs are, indeed, mere sacs, with internal cellular folds. In branchiæ also,—the second form of respiratory organ,—the essential character is the great development of surface in a small space; but in them the development of respiratory surface is towards the exterior; in the lungs it is towards the interior, either in the form of sacs or of ramified tubes. In branchiæ, as in lungs, the blood is distributed over an extensive surface, by means of the reticulated capillary vessels contained in the branchial plates and lamellæ; each lamella has its small artery, which, at the extremity, is reflected into a small vein, descending along the opposite border, while numerous capillary branches keep up anastomoses between the two. In frogs and salamanders, the motion of the blood through the capillary vessels of the sacculated lungs can be seen by means of the microscope.* The spaces between the streams of blood are, according to my observations, islets, distributed with perfect regularity, and scarcely larger in diameter than the currents themselves. The motion of the blood is seen still more distinctly in the capillary vessels of the branchiæ of the larva of the salamander.* The branches of the pulmonary arteries and veins in the lungs of salamanders, frogs and toads, according to Dr. Marshall Hall's description,† which is most exact, run constantly parallel to each other; in the angle formed by two arterial branches, there is always a venous branch, in the angles between two venous branches always a branch of an artery. In the septa of the pulmonary cells, which project into the interior of the lungs, the arterial and venous branches are so distributed that the small venous twigs run along the inner border of the septa. The ultimate branches of the arteries and veins terminate abruptly in an intermediate network of capillaries, while in all other organs, the ramification of the vessels still continues, passing imperfectly into the capillary network. The ultimate branches of the pulmonary arteries and veins are throughout perforated like sieves, to give off and receive the blood of the capillary vessels. Dr. Marshall Hall's representations of the capillary circulation in different parts are extremely interesting, particularly the 8th plate.

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* See the representations by Cowper, in Philos. Transact. abridged, vol. v. p. 331, of the lungs of the salamander, by Prevost and Dumas, in Magendie's Physiology, t. ii. and in Dr. Milligan's translation.

Destruction of the capillary network of the pulmonary cells and of the air-cells themselves by inflammation, suppuration, or structural degenerations, has two very important consequences: in the first place, diminution of the respiring surface, the effect of which may be imperfect formation of the blood, and at last wasting of the body; secondly, diminution of the number of channels through which the blood must pass, and, consequently, impediment to its course from the right to the left cavities of the heart, and thence to the general system. In warm-blooded animals, in which all the blood must pass through the capillary system of the lungs before it can arrive at the great aortic circulation, any diminution of the extent of this pulmonic capillary system must be productive of impediment to the circulation generally; and hence in patients suffering under pulmonary disease, excessive action of the heart, tendency to congestion of blood in the lungs, disposition to inflammation of these organs, and feverish excitement, are frequently observed. Any other organ might be wholly destroyed without the circulation in the rest of the body being impeded, but the loss of a portion of the lungs is a source of obstruction to the circulation generally; hence it is evident that persons suffering with pulmonary disease ought to avoid everything which might produce still greater impediment and excitement in the circulation. From this consideration may also be explained why extensive destruction of other parts, unless accompanied by a constant draining of the fluids of the body, does not always excite fever, while diseases affecting the substance of the lungs are so prone to be attended with hectic. Disorganisation in other parts ordinarily produces merely the local effects of impediments to the circulation; for instance, congestion of blood and effusion of serum, in the form of local dropsies,—such as ascites, in cases of disorganisation of the liver, &c.,—which are proportionally more rare in affections of the lungs. Gaspard has shown, that death is inevitable, and comes on very rapidly, when the circulation in the capillary vessels of the lungs is obstructed by foreign substances; for instance, by oil, mucus, metallic mercury, powdered charcoal, and powdered sulphur, injected into the veins.

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* Rusconi, Della Circolazione delle Larve delle Salam. aquat. Pavia, 1817.—Amours des Salam. aquat. Milan, 1821, in which, however, the transverse branches of the branchial laminæ are not noticed.—Steinbuch, Analecten für Naturkunde. Fürth, 1802.

† A critical and experimental Essay on the Circulation of the Blood; London, 1831; plates 5—8.

The pulmonary circulation would be perfectly isolated from that of the body, were it not that the bronchial arteries communicate with the small branches of the pulmonary artery. When the pulmonary artery and its branches are narrowed, the anastomoses between them and the bronchial arteries become enlarged.

If the chemical changes which the blood undergoes in the lungs are arrested by suspension of the respiratory movements, or by breathing irrespirable gases, the blood ceases to acquire the arterial character in the lungs, and returns of a dark red colour.

b. Greater or Systemic Circulation.

The blood, having assumed its arterial colour, flows from the pulmonary veins into the left auricle; and then commences the greater circulation, or, more correctly, the systemic portion of the circulation, in which the blood is impelled into the arteries, and thence into the capillary system of the body, where it acquires a dark red colour, and returns from the capillaries through the veins to the right side of the heart. When the auricles dilate, the blood of the pulmonary veins rushes into the left auricle, and a part of it enters the left ventricle. As soon as the muscular contraction of the ventricle has ceased, the auricle contracts, and impels the blood into the dilated ventricle, which is thus filled to its greatest capacity. During the contraction of the left ventricle which now follows, the mitral valve closes the auriculo-ventricular orifice; and the blood, forcing asunder the semilunar valves at the mouth of the aorta, flows into that vessel. Reflux from the aorta into the ventricle cannot occur, for the blood, reacted upon by the elastic coats of the vessel, presses down the pouch-shaped semilunar valves so as to close the aortic orifice. The left ventricle contracts with much greater force than the right ventricle, and its walls are in the adult, as is well known, three times thicker. The left ventricle requires greater power on account of the systemic circulation being more extensive than the pulmonic circulation, and on account of the much greater resistance which must be produced by friction in the capillary vessels of all the organs of the body.

From the aorta the blood, forced onwards at each beat of the heart by a new mass ejected from the ventricle, is distributed throughout the whole body, with the exception of the lungs, and passes through the capillary vessels into the veins.

The repeated contractions of numerous muscles during violent bodily exertion must, by the pressure excited on the vessels, interrupt the motion of the blood in a great part of the body. The more extended the operation of this cause of obstruction is, the more it resembles that interruption of the circulation which is produced by even slight obstructions in the lungs. Similar effects also are produced; the column of blood offers a greater resistance than usual to the power of the heart; the blood does not circulate freely and quickly enough through the lungs, and accumulates there; deficient aeration of the blood is in this way induced, and hence arises the labour of respiration during such great exertions, which is attributed, but less correctly, to an increased call for arterial blood. The continued contraction of the muscles in cases where single limbs are kept for a long time in action, is also accompanied with accumulation of blood in those parts.

The smaller arteries in every organ of the body before they become capillary are connected by repeated anastomoses with each other, as may be seen in any finely injected membrane; and many parts of the body receive blood by large arteries which arise from very different parts of the vascular system; thus the brain is supplied from the internal carotid and vertebral arteries, and the communication between the epigastric, mammary, and intercostal arteries is well known; similar anastomoses are met with in all parts of the body. The capillary system of all connected parts being continuous, all the vessels of the body, whether arteries or veins, are also connected through its medium. The capillary vessels of the whole body and the anastomoses of the arteries form in this manner an uninterrupted network, which receives blood from innumerable arteries, and can be supplied with blood, directly or indirectly, from different sources. In consequence of this, if the vessel which usually conveys blood to a part is obstructed, new ways of supply can be developed by the simple dilatation of already existing communications without new vessels being formed. Thus is explained the phenomenon of collateral circulation, or the restoration of the circulation through a part after obliteration of its principal vessel. At first a number of anastomosing branches are dilated, and by degrees distinct vessels, of considerable size, are developed from among them. In animals, the aorta *abdominalis* even may be tied without an absolutely fatal result, although in the two instances in which this operation was performed on man, death ensued. But all the other great arteries which are accessible in the human subject, have been tied in cases where it was necessary, with success. There are, indeed, cases recorded, proving, that when it takes place slowly, even the obliteration of the aorta immediately below the origin of the arteries of the upper part of the body does not preclude the development of a collateral circulation, the blood again finding its way circuitously to the part of the aorta below the obliteration by dilatation of anastomoses between the internal mammary, first intercostal artery, and the intercostal branches from the aorta.* In a case of this kind, described by Reynaud,† the principal communications between the subclavian artery of each side and the part of the aorta below the obliteration were effected by anastomoses of the arteria cervicalis profunda, transversalis cervicis, and intercostalis prima with the intercostal arteries of the thoracic aorta, and between the subclavian and crural arteries by direct inosculation of the internal mammary and epigastric.

The blood distributed through the arteries being impelled onwards by the new masses constantly ejected from the left ventricle, follows the course indicated through the vessels, and from the minute arteries is transmitted through the capillaries into the minute veins. This transit from arteries to veins can be observed by means of the microscope in many transparent parts: so that its existence is not merely deduced from the course which the blood is known to take in the arteries and veins, but is an object of direct observation.

The web of the frog's foot, the tail of young fishes, or of the larvæ of the salamander, frog, and toad, the mesentery of all Mammalia, the wings of the bat, the germinal membrane of the egg of oviparous animals, are all parts well adapted for the observation of the capillary circulation.‡

The red corpuscules are distinctly seen flowing from the minute ramifying arteries into a network of vessels of nearly equal size throughout, and again collecting from this network into the radicles of the veins, which, by their successive reunion, form larger trunks.

In the finest capillary vessels the red particles flow one after another in a single series, which is frequently interrupted for a time: when they flow thus singly, they appear almost colourless; when accumulated together in greater number, they appear yellow; and when in still larger quantity, they are yellowish red or red.§

The blood during its passage through the capillary vessels becomes of a dark red colour. The motion of the blood in the veins is continuous, not pulsatory as in the arteries. Those veins which are exposed to the pressure of muscles, have pouch-like valves which prevent the backward passage of the blood towards the capillaries; consequently, any pressure on the veins, instead of interrupting, favours the flow of the blood towards the heart. In the veins of parts protected from external pressure, the valves do not exist. In the pulmonary veins Mayer has discovered incomplete valves; and E. H. Weber has observed valves in the portal vein of the horse, which do not exist in man.

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* See the case observed by A. Meckel. Meckel's Archiv. 1827.

† Froriep's Notiz. 537.

‡ See the representation of the capillary vessels carrying blood, of the *area vasculosa* of the egg in Pander's Entwickelungs-geschichte des Hühnchens im Ei; of young fishes in Doellinger's Denkschift der Akad. der Wissenschaft. zu München, Bd. vii.; of the web of the frog's foot in Schultz's Lebens-process im Blute, Berlin, 1822, and in Marshall Hall's Essay on the Circulation, tab. iii.; of different parts of frogs and Mammalia, Kaltenbrunner, Exp. circa statum. sanguin. et vas. in Inflammatione, Monach, 1826; of the mesentery of the frog, Reichel, De sanguine ejusque motu, Lips. 1767, Marshall Hall, l. c. t. iv.; of the tail of the stickleback, M. Hall, l. c. t. i.; of the embryos and larvæ of fishes, frogs, and salamanders, Baumgärtner über Nerven und Blut, Freiburg, 1830.

§ The circulation in the capillaries will be more minutely described at a future page.

c. *Portal circulation.*

The blood of the spleen, intestinal canal, stomach, pancreas, and mesentery is not returned immediately to the vena cava: the veins of these organs unite to form the vena portæ, and their blood is in the first place poured by this vessel into the capillary system of the liver, and is thence conveyed by hepatic veins to the vena cava.* The hepatic capillary system is also the recipient of the blood from the hepatic artery; and hence the returning hepatic veins receive the blood both of the vena portæ and of the hepatic artery. Professor Retzius of Stockholm, informs me that he has discovered in man some minute communications between the veins of the intestines and the branches of the vena cava. When he injected the vena cava and vena portæ with fine injection of different colours, he found that the whole mesocolon and *colon sinistrum* were injected with both colours, and veins belonging to the two systems at several places formed anastomoses. The veins of the colon and mesocolon, which belonged to the system of the vena cava and entered the left renal vein, lay superficially, while those which belonged to the vena portæ lay for the most part nearer the mucous membrane. The external surface of the duodenum also had received injection from the vena cava. M. Breschet too has filled the inferior mesenteric vein from branches of the inferior cava, and Schlemm has discovered distinct communications of the inferior mesenteric vein with branches of the inferior cava about the anus. From this fact the inference may be drawn that in obstructions and congestions of blood, perhaps even in inflammations of the intestinal canal, abstractions of blood from about the anus will be of service.

The blood of the portal vein of all the vertebrata,—and the blood of the afferent renal veins in fishes, amphibia, and reptiles,—has a second time to overcome the resistance offered by the minute canals of a capillary system, before it reaches the heart. I have discovered that in the larva of the salamander, the circulation in the liver can be distinctly seen when viewed as an opaque object with the simple microscope.† The blood of the porta in its passage through the capillary vessels of the liver into the hepatic veins is seen to run in the interstices only of the acini, and the single particles of the blood can be as clearly distinguished as in transparent parts. The blood in the vena cava, as well as in all the venous canals of the liver, flows in jets, probably from the advance of the blood being checked by each contraction of the right auricle, or of the inferior vena cava itself, which in frogs can be seen to contract periodically. There is no observable difference in the colour of the blood in the vena cava, the vena portæ, and the hepatic veins.

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* See page 181.

† Meckel's Archiv. 1828. See the drawing in my treatise, De gland. penit. struct. tab. x. fig. 10.

Rate of the blood's motion.—After this general description of the circulation of the blood, it remains for us to consider the rate of its motion and the time in which it completes its entire circuit. The rate of the blood's motion in the vessels must not be judged of by the rapidity with which it flows from a vessel when divided. In the latter case, the rate of motion is the result of the entire pressure to which the whole mass of blood is subjected in the vascular system, and which at the point of the incision in the vessel meets with no resistance. In the closed vessels, on the contrary, no portion of blood can be moved forwards but by impelling on the whole mass, and by overcoming the resistance arising from friction in the smaller vessels. With respect to the time in which the circulation of a single portion of blood is completed, the following results have been deduced by Hering from eighteen experiments on horses. The time required for the passage of a solution of ferrocyanate of potash of different strengths, which is mixed with the blood, from one jugular vein (through the right side of the heart, the pulmonary circulation, the left cavities of the heart, and the general circulation) to the jugular vein of the opposite side, varies from twenty to twenty-five or thirty seconds. The same substance was transmitted from the jugular vein to the great saphena in twenty seconds; from the jugular vein to the masseteric artery in between fifteen and thirty seconds, to the facial artery in one experiment in between ten and fifteen seconds, in another experiment in between twenty and twenty-five seconds; in its transit from the jugular vein to the metatarsal artery it occupied between twenty and thirty seconds, and in one instance more than forty seconds. The result was nearly the same whatever was the rate of the heart's action. These results do not, however, accord with the estimate of the time occupied by the circulation, which is deduced from the quantities of blood generally supposed to be contained in the body, and from the quantity which can be advanced at each beat of the heart. According to Wrisberg, a woman lost by a fatal flooding twenty-six pounds of blood, and in the beheading of a full-blooded woman twenty-four pounds of blood were collected. And if we suppose two ounces of blood to be impelled forward at every beat of the heart, it would require one hundred and sixty beats for the circulation of twenty pounds; and for the circulation of ten pounds of blood, which Herbst[*] calculates to be the quantity of blood contained in the human body, eighty beats of the heart would be required. It may, therefore, be admitted with more certainty, that the circulation of blood in man is completed in from eighty to two hundred and fourteen beats of the heart, or in from one to two minutes.[†]

The time in which a portion of blood performs its course from one side of the heart to the other, varies much according to the organ it has to traverse. The blood which circulates from the left ventricle, through the coronary vessels to the right side of the heart, requires a very far shorter time for the completion of its course than the blood which flows from the left side of the heart to the feet, and back again to the right side of the heart; so that the circulation from the left to the right cavities of the heart forms a number of arches, varying in size *ad infinitum*, the smallest of these arches being formed by the circulation through the coronary or nutritious vessels of the heart itself. The course of the blood from the right side of the heart, through the lungs, to the left, is shorter than most of the arches described by the systemic circulation, and in it the blood flows, *cæteris paribus*, much quicker than in most of the vessels which belong to the aortic circulation. Although the quantity of blood contained in the greater circulation of the body, on account of its greater extent, is much more than the quantity within the lesser circulation, yet at any imaginary spot of the pulmonary artery, in a certain space of time, just as much blood passes as at any imagined point in the aorta; for, although in the capillaries the circulation is subject to great variation, in the main trunks of the closed circuit no more blood can leave one point than finds place at another point. If, therefore, we suppose the capillary vessels between arteries and veins to be equally large in the lungs and the rest of the body, a far greater number of them must be included in the same space in the lungs than in other parts of the body. This is found by observation to be the case, for in the lungs of frogs the interspaces between the capillaries are scarcely larger, in man even smaller perhaps, than the diameter of the capillary vessels themselves. This has been shown by Cowper, Wedemeyer, Marshall Hall, Prevost and Dumas, Weber (in the human subject), and more recently by myself.

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[*] De sanguin. quantit. Göttingen, 1822. For an account of Valentin's experiments on the quantity of blood contained in the body, see page 140.

[†] See Burdach, Physiologie, iv. p. 101—253.

Lastly, it is to be remarked, that the rapidity of the motion of the blood in the small branches must necessarily be less than in the trunks generally, if, as seems to be the case, the aggregate sectional area of the branches of a stem is larger than the sectional area of the stem itself, although this must not be regarded as strictly proved. If, however, we imagine all the small vessels of any single organ united into one trunk, and the blood to flow in a circular course from the artery into this trunk, and thence through the vein into the artery again, thus forming a closed circle, although the movement of the single particles of the blood will be more rapid in those parts of the circle where the tube is narrow, and slower where the tube is wider, still within a given time the same volume of blood must pass each and every point of the circle.

CHAPTER III.

OF THE HEART CONSIDERED AS THE CAUSE OR PROPELLING POWER OF THE CIRCULATION OF THE BLOOD.

THE heart, like other muscular organs, contracts when irritated mechanically, or by galvanism. Sœmmering, Behrends, and Bichât denied the influence of galvanism on the heart; but I have frequently repeated Humboldt's and Fowler's experiments, and have obtained the same results as they did. In both frogs and dogs, in which the heart had ceased to act, I have re-excited its contractions by means of a single pair of plates, or a weak galvanic pile. But the heart, like most other organs which are endued with involuntary motion only, such as the intestinal canal, is distinguished from voluntary muscles, by the irritation exciting in it not a single contraction, but a succession of periodic contractions.

The heart being thus, like all muscles, excited to action by a stimulus, it is very natural to conclude that the blood contained in its cavities, supplies the stimulus during life; and this supposition is strengthened by the circumstance of the heart's action becoming more feeble in proportion as the quantity of blood it contains is diminished.

To explain why the contractions are rhythmic, it has been said that the same act—the systole—by which the heart expels its stimulus—the blood—in one direction, causes its cavities to be again filled with blood from the veins. In the same way the alternation of the contractions of the auricles and ventricles may be explained, since the one cavity by its contraction gives rise to the filling of the other. But although a certain quantity of blood and a certain distension of the cavities of the heart is so necessary for the preservation of its action, and although any mechanical dilatation of the heart from within must have the effect of exciting it to contract; yet, since it continues to contract, though feebly, when emptied of its blood, it is evident that the stimulus of the blood in its cavities cannot be the primary cause on which its action depends. The regular succession of the heart's contractions may be explained in another way. The heart, at each systole, expels the blood from its nutritive vessels, and when the contraction ceases, these vessels are again filled by the agency of the elastic coats of the arteries, which exert a constant pressure on the blood contained in them. Now, the re-filling of the minute vessels of the heart with blood during each diastole may be supposed to become the cause of a fresh contraction. This hypothesis, however, is refuted by the same fact as the former; for the heart, particularly that of Amphibia and Fishes, continues to contract regularly—the auricle and ventricle in the same succession—when it is removed from the body and emptied of its blood; in Amphibia, indeed, the action continues for hours. This might, however, be explained by attributing it to the stimulus of the atmosphere, which, although its action is constant, may nevertheless excite periodic contractions.* But the action continues in a vacuum, and an external cause like the air does not explain the regular succession of the ventricular contractions after those of the auricles. The cause, then, must be in some way connected with the organisation of the heart, and with the constant mutual action which is going on between the blood in the capillaries, or between the cardiac nerves, and the texture of the heart; and whether this cause be constant in its action or periodic, the rythmic contractions of the heart are equally explicable.(*a*) The nature of the cause, however, cannot be determined in the present state of our knowledge.

1. *Influence of respiration on the heart's action.*—When the chemical changes effected in the blood in the lungs are interrupted, —whether it be from the respiratory movements being checked, in consequence of lesion of the nerves on which they depend,—from mechanical impediments to the movements, or from the inhalation of irrespirable gases,—the vital action of all the organs of the body is depressed; and, in the higher animals, is indeed soon annihilated. It is true, as Bichât and Emmert have shown,† that the blood no longer arterialised, continues for a time to move in the arteries; and the heart, after the apparent death of the body, generally continues to beat slowly and feebly even in warm-blooded animals during more than half an hour; nevertheless, interruption of respiration enfeebles its action to such a degree, that the circulation very soon ceases; while, on the other hand, if, after the respiratory movements have been interrupted by injuries of the encephalon, but particularly of the medulla oblongata, or by poisoning, artificial respiration be performed, the circulation may be maintained for a much longer period, whatever be the animal on which the experiment is instituted. In a dog beheaded after tying the cervical vessels, and in which artificial respiration was kept up, Brodie saw the heart continue to beat for two hours and a half, at the rate of thirty-five pulsations in a minute; and, in another dog, an hour and a half at the rate of thirty pulsations in a minute;‡ so that the influence of the respiration on the heart's action seems to be greater than that of the nervous system. In cold-blooded animals, however, this influence of the respiration, or of arterialised blood, on the heart is much less; for frogs, the lungs of which I had tied and removed, have lived thirty hours, the action of the heart still continuing; while, after destruction of the brain and spinal marrow in these animals, the action of the heart ceases much sooner, namely, in six hours; consequently, either the function of respiration in frogs can be performed by the skin when the lungs are lost, or the brain and spinal marrow are in these animals much more necessary to the maintenance of the heart's action than respiration. The latter is most probably the more correct explana-

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* In accordance with the law of excitability, stated at page 60.

(*a*) Dr. J. K. Mitchell, of the Jefferson Medical College, has seen the heart of a sturgeon, after he had excised it from the body, and inflated and hung it up to dry, begin again to move, and to contract regularly for ten hours.

† Reil's Archiv. v. 401.

‡ Ibid. xii. p. 140.

tion; for when they can breathe neither by the lungs nor by the skin, namely, when they are immersed in pure hydrogen, frogs live more than twelve hours, as I have myself witnessed. Though here it must be remembered, that one great object of respiration is the removal of carbonic acid from the blood, and that this is fulfilled, in a great measure, when frogs are confined in hydrogen gas. The final cessation of the heart's action, in cases where respiration is suspended, may indeed depend chiefly on the change which ensues in the nervous system when it no longer receives red blood.

The disturbance of the circulation, after interruption of the respiration in the higher animals, is certainly not produced by the collapse of the lungs, the experiments on the production of respiration in hydrogen offering an impediment to the passage of the blood; for the motion of the blood in the arteries, as Bichât and Emmert showed, continues in such cases for a certain time undisturbed.

Dr. Goodwin attributed the depression of the circulatory powers, after interruption of the respiration in the higher animals, to the circumstance of the left ventricle ceasing to receive arterial blood, and supposed that the influence of this kind of blood was indispensably necessary to the action of the left side of the heart. To this Bichât replied, that in animals of which the respiration is suspended, the dark blood coming from the lungs to the heart does not cause the *immediate* cessation of the contractions. This and other arguments adduced by Bichât* are not conclusive. It is not, however, at all probable that each side of the heart has a specific irritability for different kinds of blood; for in the fœtus, in which the auricles communicate by the foramen ovale, and in which there is no pulmonary respiration, but only some peculiar change effected in the blood in its passage through the placenta, both sides of the heart receive the same kind of blood. If the immediate action of bright red blood on the heart is really necessary to the maintenance of its action, Bichât's explanation is much the more probable. He supposes that interruption of the respiration deprives the heart of its irritability, by preventing the supply of arterialised blood to the muscular fibres through the coronary arteries, which now carry dark venous blood. But although it appears certain that arterial blood does exert an influence on the heart's action, yet the relative degree in which this influence and that of the nerves are necessary cannot be estimated; for all disturbances of the respiration produce corresponding disturbance in the action of the nervous system.

2. *Influence of the nerves on the heart's action.*—The influence of the passions, and other affections of the nervous system, on the heart's action, is matter of constant observation. All sudden passions at first disturb and then accelerate its action; the contractions becoming much more vigorous and frequent under the influence of the exciting passions, while they are rendered feeble, at the same time that they are accelerated by the depressing passions.

Nevertheless, some persons have denied the dependence of the heart on nervous influence. Thus Haller denied it, on the grounds that the heart continues to contract when removed from the body, and that irritation of the cardiac nerves does not produce those convulsive actions to which irritation of the nerves of other muscles gives rise.

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* Recherches sur la vie et la mort.

The first researches on this subject are those of Sœmmering and Behrends on the cardiac nerves, in 1792, which tended to prove that the substance of the heart receives no nerves, and that all the fibres of the cardiac nerves in the heart are distributed to the coats of the cardiac vessels. This seemed to confirm Haller's doctrine of the contractility of the muscles, namely, that the power is inherent in the muscles themselves, and not dependent on the influence of the nerves, and that the nerves excite contractions in the muscles in the same way as external stimuli, whether mechanical, electrical, or chemical; and it also seemed to prove that the heart not being endowed with the nervous stimulus, is excited to motion by the blood itself. The statement of the same experimenters, that galvanism produces no contraction of the heart, while it has this effect in all muscles provided with nerves, seems to confirm this view still more strongly.

But Scarpa has demonstrated that the cardiac nerves are really distributed in great abundance to the muscular substance of the heart. Humboldt, Pfaff, Fowler, and Wedemeyer have succeeded in producing contractions of the heart by means of galvanism; and I have repeated their experiments with success in frogs as well as in mammalia. I have not only excited immediate contraction in a frog's heart which had ceased to pulsate, by means of a single pair of plates, but with a battery of forty pairs of plates have caused the heart of a dog in which the pulsations had ceased to contract most actively. Humboldt[*] states that by galvanising the cardiac nerves he has produced contractions of the heart. The nerves, as Burdach remarks, may act as moist conductors when one wire of the battery is applied to them, and the other to the heart; Burdach,[†] however, actually saw the contractions of the heart of a dead rabbit become stronger when he applied both wires of the battery to the cervical portion of the sympathetic nerves, or to the inferior cervical ganglion. Such experiments on the motor power of the nerves are not conclusive, unless the wires are applied to the nerves alone, and unless the galvanic action is very weak. Strong discharges may be transmitted from one point through moist conductors to distant parts, and in that way might be conducted by the nerves to the heart. For this reason the experiments of Burdach, in which he re-accelerated the action of the heart of a dead rabbit, after it had begun to fail, by touching the sympathetic nerves with caustic, potash, or ammonia, are the more interesting; and particularly so, since, in a dead rabbit, painful impressions can no longer have any effect in changing the action of the heart. I did not, however, myself, succeed in obtaining the same result on repeating this experiment. The experiments which Brachet[*] and others have instituted on living animals, for the purpose of determining the irritability of the nerves, are of no value with regard to the heart, its action being so much affected by painful impressions.

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[*] Ueber die gereizte Muskel-und Nerven-fäser, i. 342.

[†] Physiol. iv. 464.

Another phenomenon which distinguishes the heart from other muscles is the persistence of its rhythmic contractions in their regular order in the different cavities, even when removed from the body and emptied of its blood. This cannot be explained otherwise than by supposing the heart under these circumstances to retain with its nerves some specific nervous influence.[†] The influence of the nerves, therefore, seems to be the ultimate cause of the contractions of the heart; as the great effect which irritations of the brain and spinal marrow, and passions of the mind, have in modifying its action also tends to show. If it were possible to destroy the vital function of the nerves, without at the same time depriving the muscles of their power of contraction, this question might be set at rest; but unfortunately the narcotic agents, which, when applied to the nerves, take from them their property—when irritated—of exciting contractions in the muscles to which they are distributed, render the muscles incapable of exercising their contractile power when the nerves are irritated. Opium applied to the heart of a frog soon puts a stop to its motion; this effect being produced, as Henry has shown, very rapidly when the narcotic is brought into contact with the inner surface of the organ, but more slowly when it is applied merely to its outer surface. It is evident, however, that the nerves have a great share in the heart's action, from the sudden disturbance and cessation of the rhythmic movements when the whole spinal marrow is suddenly destroyed.

Influence of the brain and spinal cord on the heart's action.—The inquiry respecting the part of the nervous system whence this influence on the heart is derived, whether from the cardiac nerves and sympathetic system, or through the medium of these from the spinal marrow and brain, was originated by Bichât. Before entering into this inquiry, it will be necessary to give a sketch of the principal divisions of the nervous system. The functions of the two systems of nerves were more exactly defined by Bichât. The nerves arising from [connected with] the brain and spinal marrow have, for the most part, the power of exciting voluntary motion in the muscles to which they are distributed, but lose this power when their connection with the nervous centres is cut off; and the nerves arising from the spinal marrow are also deprived of the power of communicating volition when their connection with the brain is interrupted by injury of the spinal marrow. Nevertheless, one of these nerves thus cut off from its source of volition—the nervous centres,—still retains for a time the power of exciting involuntary contractions of muscles when it is irritated mechanically or by galvanism.

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[*] Recherches sur le système ganglionaire.

[†] Remak (Casper's Wochenschrift, No. X. 1839) states, that the minute branches of nerves which he had traced into the muscular substance of the heart in man, as well as in many mammiferous animals, consist like other parts of the sympathetic nerve of the peculiar gray organic nervous fibres beset with small ganglia (see the fourth chapter of the second section in the book on the Nervous System). And by the presence of these numerous ganglia, or centres, of nervous influence, he explains the continuance of motion in the heart after its separation from the body. But it must be remarked, that Valentin denies the existence of these gangliated organic fibres.

The parts to which the branches of the sympathetic nerve are distributed, for example, the heart, intestines, and uterus, are endowed by them with involuntary motion only. The sympathetic nerve is connected with the brain and spinal marrow indirectly only, through the medium of the cerebro-spinal nerves. Bichât called the cerebro-spinal nerves "the nerves of animal life," the sympathetic nerves he styled the "nerves of organic life," and ascribed to the latter a certain independence of the brain and spinal marrow, regarding the ganglia and plexuses as their nervous centres. Recently a discovery has been made, which in the history of physiology ranks second only to the discovery of the circulation of the blood; it is, that the nerves which arise by an anterior and posterior root from the spinal cord derive their power of exciting contractions in the muscles from the anterior root, and their power of sensation from the posterior root. This discovery is due to Charles Bell. I have since proved that mechanical and galvanic stimuli applied to the posterior root have no power of exciting contraction in the muscles to which the spinal nerves are distributed. Scarpa[*] not long since endeavoured to show that the connection of the sympathetic nerve in the chest with the commencement of the spinal nerves, implicates the posterior roots only of the latter nerves, and not their anterior roots; and, consequently, that the sympathetic nerve can neither be intended to communicate motor power to the heart from the spinal marrow, nor possess motor power itself. The researches of Wutzer and myself, as well as those of Retzius and Meyer, have shown, however, that Scarpa is incorrect, and that the communicating branches between the sympathetic nerve and the spinal nerves receive their fibres from the anterior motor, as well as from the posterior sensitive roots of the spinal nerves.[†] The principal experiments made with a view to elucidate the influence of the spinal cord and brain on the motions of the heart, are those of Legallois, Philip,[‡] Treviranus, Nasse, Wedemeyer, Clift, and Flourens.

New facts were brought forward by Legallois[§] to prove that the cause of the heart's action resides in the spinal cord alone.

Dr. Wilson Philip[||] has shown, however, that the experiments of Legallois have not explained the whole relation between the brain, spinal cord, and sympathetic nerves. When an animal is deprived of voluntary motion and sensation by a blow on the occiput, respiration ceases, but the heart's action still continues, and may be supported for a long time by keeping up artificial respiration. If the spinal cord and brain are now wholly removed by the knife, the heart nevertheless still continues to beat, though feebly; and even when the spinal marrow and brain are destroyed by a hot wire, the heart's action generally continues. Hence Wilson Philip is led to a conclusion the very opposite of that of Legallois,—namely, that the heart's action is essentially independent of the brain and spinal marrow; although, as his experiments seem to show, the influence of both brain and spinal cord has a great share in the sympathetic affections of the sympathetic nerve and heart.

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[*] Scarpa, De gangliis nervorum, deque origine et essentia nerv. intercostalis; ad H. Weber. Annal. univers. d. medicina. Magg. e. Giugn. 1831.

[†] See Meckel's Archiv. 1831, i. p. 85. 260.

[‡] Inquiry into the Laws of the Vital Functions.

[§] Exp. sur le principe de la vie. Paris, 1812.

[||] Inquiry into the Laws of the Vital Functions.

The conclusions deduced by Flourens from his experiments on fishes were, that the action of the heart depends solely on the respiration, and ceases when the respiratory movements are put an end to by injury of the portion of the nervous centre on which these movements depend; and therefore that in fishes, the respiratory movements of which depend on the medulla oblongata only, circulation continues after injury to other parts of the cord. Dr. Marshall Hall,[*] however, has seen the circulation in fishes endure for a long time after destruction of the medulla oblongata. But he allows that the heart is in some measure dependent on the spinal cord and brain.[†]

The experiments of Legallois, Philip, and others, considered in connection with facts already known, namely, that the heart when removed from the body still continues to beat for a long time (as is strikingly seen in the hearts of reptiles, amphibia, and fishes); that depressing affections of the nervous system weaken the force of the heart's action; and that, with nervous fainting, feebleness of the circulation is combined, appear to warrant the following inferences:—1. That the brain and spinal marrow have a great influence on the motion of the heart; and that its movements may, through their agency, be accelerated or retarded, depressed or invigorated. 2. That the heart's action still continues for a certain time after simple removal of the spinal cord and brain from the body. (Flourens observed that pulsation of the carotids continued for more than an hour in rabbits under these circumstances, artificial respiration being kept up.) That, under these circumstances, however, the heart's motions are much feebler, and the circulation not maintained perfectly for any long period. 3. That even when the heart is cut from the body, and consequently separated from the greatest part of the sympathetic nerve, its contractions still continue for a short time.

The heart is not so much dependent on the influence of the brain and spinal marrow that the removal of these organs immediately annihilates its power of motion. The cardiac nerves, under such circumstances, still retain a portion of the motor influence, and even in the small part of these nerves which can be contained in a heart cut from the body, there still remains sufficient nervous power to enable the organ to continue its motions for a short time. But the brain and spinal marrow must nevertheless be regarded as a principal source of the nervous influence; for their destruction enfeebles the heart's action to such a degree, that, although it is continued for a considerable time, its force is not sufficient to keep up the circulation. The only mode of ascertaining the degree in which the heart is subject to this influence is that adopted by Nasse. He measured the height of a stream of blood which issued from a divided artery in the normal state, then destroyed the spinal cord or single parts of it, and he found that the height of the stream of blood had in a few minutes diminished, and in degree proportioned to the injury.

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[*] Essay on the Circulation.

[†] On this subject consult Treviranus, Biol, iv. 644.—Clift, Phil. Trans. 1815.—Wedemeyer, Physiol. Untersuch. über das Nervensystem und die Respiration; Hannov. 1817.—Nasse, in Horn's Archiv., 1817, 189.—Flourens, Versuche über die Eigenschaften und Verrichtungen des Nervensystems; Leipz. 1824.—Nasse, Untersuch. zur Lebensnaturlehre; Halle, 1818; which contains an elaborate review of the experiments of Legallois, and a luminous statement of the whole subject. See also Lund, Physiol. Resultate der Vivisect. neuerer Zeit; Kopenh. 1825, 162.

The sympathetic nerve, however, is certainly not dependent on the brain and spinal marrow in the same degree as the cerebro-spinal nerves. This is evident from the single fact, that in fishes the contractions of the heart continue for the space of half a day after destruction of the brain and spinal marrow.

Circulation in acephalous monsters.—In monsters in which brain and spinal cord are wanting, the circulation seems to be still more independent of the nervous centres; but the anatomy of these monsters is not at present known with sufficient accuracy for any conclusion with regard to the present question to be drawn from them. In hemicephalous monsters the brain has mostly been destroyed by hydrocephalus, and the same disease may also destroy the spinal marrow.

In acephalous monsters the heart also is generally, but not always absent; and the vascular system consists generally only of two systems of vessels connected, not by their trunks, but only by their capillaries, the umbilical vessels being branches of these trunks.* Winslow's case is the only one in which the umbilical vein was continuous with the arterial trunk, resembling that condition of the embryo in which the heart is merely the part at which the venous trunk makes a bend and is continuous with the arterial. Brachet† has collected all the accounts of acephalous monsters in which the spinal marrow also was deficient.‡ The case mentioned by Ruysch,§ in which an inferior extremity was connected with the placenta of a well-formed fœtus, is particularly remarkable. Emmert‖ has described a product of conception which consisted almost entirely of an extremity hung to an umbilical cord, and contained vessels, arteries, and veins, and a short stump of spinal marrow.¶ There is no difficulty in explaining the circulation of the monster without heart and spinal marrow, when its vessels are merely branches of the vessels of the umbilical cord of another fœtus, as was the case in the monster described by Rudolphi,[*] which consisted of a head only, and in the case which I observed myself of a head which was connected by arteries and veins with the umbilical vessels of a completely formed child.[†] Rudolphi, to explain the circulation in other monsters without heart, says that the blood of the mother passes to the fœtus through the umbilical vein, which is distributed through it like an artery, and that the arteries of the fœtus bring back the blood to the umbilicus and placenta.[‡] This explanation, however, is contradicted by anatomy, for the vessels of the fœtus or placenta do not really communicate with those of the mother.

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* Tiedemann, Anat. d. Kopflos. Missgeburt; Lanshut, 1813.

† Loc. cit.

‡ See also Meckel, Pathol. Anat. i. Elben, De Acephalis; Berol. 1821.

§ Thesaur. Anat. ix. p. 17. tab. i. fig. 2.

‖ Meckel, Archiv. vi.

¶ A similar case is described by Hayn, Monstri unicum Pedem referentis Descriptio anatomica. Berol. 1824.

Influence of the sympathetic nerve on the heart's action.—Ackermann strangely asserted, without any grounds, that the sympathetic nerve is the part first formed in the fœtus. The very meritorious Rolando has also deserved censure in declaring the first traces of the vertebræ, at the side of the spinal cord in birds, to be ganglia of the sympathetic nerve.

Not only brain and spinal cord, but all the organs in their state of vital action, and consequently the whole system, react upon the sympathetic nerve through the medium of the nervous fibrils accompanying the blood-vessels, and excite its peculiar motor power. The constant source of the heart's contractility is, therefore, *primo loco* the motor power of the sympathetic nerve. But the maintenance of this power, and its excitement, are dependent not only on the brain and spinal cord, but probably on the vital stimulus, transmitted by all the organs of the body, through the medium of the nerves accompanying the vessels, to the central portions of the sympathetic. Hence it is that a local affection excites a general feeling of illness in the whole body, and that a very violent local disease can affect the heart's action and the pulse.

The modifications which the minute radicles of the sympathetic in any part undergo from violent local disease, and the reaction of these modifications on the central parts of the sympathetic system,—the cardiac nerves and plexuses,—as well as on the brain and spinal cord, seem to have a main share in the phenomena which we call fever.

No observations have at present been made on the influence of particular portions, or regions of the sympathetic nerve, on the heart's action. The only facts bearing on this point are those ascertained by Pommer,[§] who found in fifteen experiments that the division of the sympathetic in the neck had generally no important consequences. Several cerebral nerves being intimately connected with the sympathetic nerve, and the nervus vagus in particular having an essential share in the composition of the cardiac plexus, it would be very desirable to know, also, what influence these nerves exert on the heart's action. Emmert observed that division of the nervus vagus produces but very slight disturbance in the circulation; and Bichât and Legallois with justice remark, that the effects produced on the heart's beat, which are by no means considerable, cannot with certainty be ascribed to the division of the nerve, since the mere pain and fear produced by the operation might give rise to them.

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[*] Abhandl. d. Akad. zu Berlin, 1816.

[†] Müller's Archiv. 1834, 179. See also the description of the rudimentary monster represented by Gurlt. (Pathol. Anat. 2. Bd. tab. 16. fig. 1—4.) And the dissection of an imperfect fœtus which was connected by its vessels with another perfect fœtus, by Sir A. Cooper. Guy's Hospital Reports, vol. i.

[‡] Encyclop. Wörterbuch der med. Wissensch. i. 126.

[§] Beiträge zur Natur-und Heilkunde; Heilbronn, 1831.

CHAPTER IV.

OF THE INDIVIDUAL PARTS OF THE VASCULAR SYSTEM, AND THEIR RESPECTIVE SHARES IN THE CIRCULATION OF THE BLOOD.

Of the arteries.—The middle coat of arteries is composed of fibres and bundles of fibres, surrounding the vessel in a circular direction, which differ in chemical and physical properties as well as in form from muscular fibres. The fibres of the middle coat of arteries agree in every respect with those of the elastic tissue found in other parts, such as the ligamentum nuchæ of mammalia, the ligamenta flava of the vertebræ, the yellow ligaments of the larynx, the yellow fibres of the membranous part of the trachea and bronchi, the elastic ligament of the wing of birds, the elastic ligaments of the last phalanx of the toes in feline animals, &c. The elastic tissues are distinguished from all other tissues, not only by their yellow colour, but more especially by the character of their fibres, which, unlike all other known animal fibres, have been observed by Lauth[*] and Schwann[†] to divide and anastomose. In chemical properties the elastic tissues resemble the cellular and other tissues which yield gelatin by boiling, and of which the solution in acetic acid is not precipitated by ferrocyanide of potassium. Eulenberg[‡] has recently discovered that, after long-continued (many days') boiling, they give out some gelatin, which differs, however, from the ordinary gelatin, being more like the "chondrin" which I have remarked to be afforded by cartilages and the cornea in boiling. The elasticity of the middle coat of arteries, the influence of which on the circulation of the blood will be described, is preserved for many years in alcohol. A portion of the aorta of a young whale, which I have received from my friend Professor Eschricht, is still highly elastic, although it has been several years in alcohol. Thin laminæ cut from it, are found, when extended, to have the same elasticity as caoutchouc. All elastic tissues retain their elasticity in the same way; this I have ascertained by experiment on all the elastic ligaments above-mentioned, after they had been kept up in alcohol. In fact, the contractility of the fibrous coat of arteries is physical elasticity, not a vital property; it is exerted only after previous distension; for example, after the distension of the arteries by the blood impelled into them by the heart's contraction. The internal coat of arteries also consists of similar elastic fibres, which are disposed either longitudinally or irregularly in all directions, and become more minute as they are nearer to the inner surface of the vessel, until at length distinct fibres can no longer be perceived. A very delicate layer of epithelium scales, with oval nuclei, occupies the inner surface.* The external coat, both of arteries and of veins, contains some elastic fibres, but the middle coat of veins is destitute of them. In the crural vein of the ox, Schwann found a thick middle coat formed of transverse fibres; but these were fibres of cellular tissue; within this, however, there was an extremely thin layer of longitudinal proper elastic fibres.†

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[*] Müller's Archiv. 1835, p. 4.—L'Institut, Jan. 14, 1834.

[†] Eulenberg, de Telâ Elasticâ. Berol. 1836.—Müller's Archiv. 1836, p. xxv.

[‡] Loc. cit.

Cause of the pulse.—By each contraction of the ventricle a fresh portion of blood is propelled into the aorta, and the rapidity and force of the circulation in the arteries is increased. The periodic acceleration of the motion of the blood in the arteries thus produced, was proved by the following experiment of Dr. Hales: having introduced a tube into an artery, he observed that at every beat of the heart the blood rose within the tube one or even several inches. The blood is not able to escape from the arteries as quickly as it is forced into them by the ventricle, on account of the resistance it experiences in the capillaries. Hence it exerts a pressure on the elastic coats of the vessels, and thus gives rise to the pulse, which being dependent on the contraction of the ventricle, is, in general, synchronous with it. In consequence of the pressure exerted by the blood, the coats of the arteries become extended at each systole of the heart, while, during the diastole, they recover their former state by virtue of their elasticity. The extension of their coats takes place both in length and in the direction of their diameter, but the elongation is by far the most considerable. A necessary consequence of their elongation is, that they change their position and become curved; but they straighten themselves and recover their original situation when the ventricular contraction has ceased. Rudolphi, Laennec, Arthaud, Parry, and Doellinger, denied that the arteries undergo any dilatation. We have, on the other hand, the authority of Bichât, Von Walther, Tiedemann, Meckel, Hastings, Magendie, and Wedemeyer, for its existence: and in the entire course of the pulmonary artery in the lung of the frog, the dilatation, as well as the incurvation of the vessel, can be seen with the greatest distinctness. I have also witnessed it in the abdominal aorta of the frog, and once quite satisfactorily in the aorta of the rabbit. The dilatation must, however, be less considerable than the elongation, for it is not always observed with distinctness.‡ Poiseuille,§ indeed, has measured the degree of this dilatation of the arteries. His experiment was ingenious: he laid bare the common carotid of a living horse for the space of three decimeters, or about twelve inches, and passed beneath it a tube of white metal, open at one side, which he afterwards closed by means of a narrower portion, so as to complete the tube; he then stopped the ends with wax and fat, and filled the interior of the tube around the artery with water, by means of a glass tube which was connected with the metallic tube. At every pulsation the water rose 70 millimeters* in the glass tube, the diameter of which was 3 millimeters, and fell again the same distance during each pause. The included portion of artery measured in length 180 millimeters, and its capacity equalled 11,440 cubic millimeters; and since at every beat of the heart it underwent an increase of capacity equal to a column of water 3 millimeters in diameter and 70 millimeters in height, or about 494 cubic millimeters, it follows that it was dilated about $\frac{1}{23}$ of its capacity.

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* Henle, Müller's Archiv. 1838, p. 127.

† Schwann, Encyclop. Wörterbuch. der med. Wissensch. Art. Gefässe. Eulenberg, De Tela Elasticâ. Berlin, 1836.

‡ See the observations of E. H. Weber, Hildebrandt's Anat. t. iii. p. 67.

§ Magendie's Journal, t. ix. p. 44.

The pulse in different arteries.—It was asserted by Bichât, and is commonly admitted, that the pulse is synchronous in all the arteries of the body, whatever be their distance from the heart.

Weitbrecht, Liscovius, and E. H. Weber† have shown, however, that this is not the case. The pulsation of the arteries near the heart is synchronous with the contraction of the ventricle. But at a greater distance from the heart the arterial pulse ceases to be perfectly synchronous with the heart's impulse, the interval varying, according to Weber, from one-sixth to one-seventh of a second. Thus, the pulse of the radial artery even is somewhat later than that of the common carotid. The pulse of the facial, at about the same distance from the heart, is isochronous with that of the axillary artery; while the pulse is felt somewhat later in the metatarsal artery on the dorsum of the foot, than in the facial artery and common carotid. Weber‡ has explained the cause of this difference. If the blood circulated in perfectly solid tubes, whose walls admitted of no extension, the impulse of the blood, driven by the ventricle into the arteries, would be communicated even to the end of the column of blood, with the same rapidity with which sound is propagated through this fluid,—much quicker, namely, than in atmospheric air; the pressure of the blood would be transmitted to the finest extremities of the arteries, with no perceptible loss of time. But, in consequence of the arteries admitting of some extension, particularly in length, the impulse given to the blood by the heart distends first merely the arteries nearest to the heart. These, by their elasticity, again contract, and thus cause the distension of the next portion of the arterial system, which also, in its turn, by contracting, forces the blood into the next portions, and so on; so that a certain interval of time, although a very short one, elapses before this undulation, resulting from the successive compression of the blood, and the dilatation and contraction of the arteries, reaches the most distant parts of the system. Weber compares this action to the propagation of the undulations produced by a stone thrown into a lake; in which case, likewise, the undulations are not transmitted with the rapidity of sound. The rapidity of the transmission of undulations in water twenty-three inches deep is, according to the experiments of the MM. Weber,* five and a half Paris feet in a second. Bichât confounded the motion of the undulations in a river with the movement of the water itself, and believed the pulse to be produced, not by the progressive undulations, but by the impulse communicated at the same moment to all the arterial blood. The motion of undulations always depends on the oscillations transmitted from the point where the impulse is applied, and never on the progressive motion of the fluid itself. The water of an undulation rises and falls, but remains in the same place, while the undulation and the oscillation of its particles are propagated onwards in successive portions of water. Thus it is that very light bodies on the surface of undulations though they rise and fall, remain in the same spot, while the undulation is progressive.

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* A millimeter equals 0·03937 of an English inch.

† In his Treatise De Pulsu non in omnibus Arteriis plane synchronico.

‡ Adnotat. Anatom.

For the transmission of the pulse a continuous column of blood is required; if the arteries were empty at different points, the transmission of the pulse, as Weber remarks, would be much slower, or quite interrupted; for the parts of the arteries which contained no blood must be filled by the current of the blood before the impulse could be transmitted onwards, and the velocity with which the blood itself moves is much less than that with which the impulse is propagated. Hence Weber explains the fact of the pulse, in an artery affected with aneurism, not being synchronous with the heart's action and with the pulse of other arteries; for the coagulum in the aneurismal sac, or spaces in it which are not quite filled with blood, may impede the propagation of the impulse.

The *arterial pulse*, then, we may conclude, *is the effect of the oscillation propagated along the coats of the arteries, and in the blood itself, in consequence of the pressure exerted upon the column of blood in the aorta by the heart in its contraction.*†

Motion of the blood in the arteries.—The elastic coat performs an important use, as Weber remarks, in rendering the motion of the blood continuous, by its reacting in the intervals of the heart's action on the blood forced into the arteries at each systole. The blood escapes from a divided artery in a continuous stream, although this stream is accelerated at intervals, and the periodic acceleration becomes less perceptible in proportion as the arteries diminish in size. Weber remarks, that in this respect the vascular system resembles the fire-engine; in which the water is made to flow in an uninterrupted stream by the elasticity of the air in the air vessel, which continues to act upon the water, while the piston remits its pressure.‡

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* Wellenlehre. Leipsic, 1825, p. 188.

† Weber, Adnotat. anatom. et physiol. prolus. i.

‡ Weber, l. c. De utilitate parietis elastici arteriarum. Hildebrandt's Anatomie, iii. p. 69.

The action of the regulator of bellows is the same. By ossification of the arteries this elasticity is lost, and a disposition to apoplexy, gangrene, &c., is the consequence.

Contraction of arteries in proportion to the volume of their contents.—By virtue of their elasticity, arteries possess the remarkable property of diminishing their capacity in proportion to the quantity of blood they contain, and in proportion as it escapes from them when divided; for this reason, when an artery is divided, the stream of blood which flows from it becomes gradually smaller. In a horse, which Hunter let bleed to death, he found that the aorta had contracted to the extent of more than $\frac{1}{10}$th of its diameter; the iliac artery, $\frac{1}{6}$th; the crural artery, $\frac{1}{3}$d; and that arteries of the thickness of the radial in man were completely closed.* The more forcibly the heart acts, the more are the arteries extended, and the more blood do they contain in proportion to the veins. On the contrary, when the heart's action is feeble, the coats of the arteries are more able to resist the impulse of the blood; they become less distended, and, consequently, contain proportionably less blood than the veins. This is what takes place just before death, and it is one cause of the absence of blood in the arteries after death; they are, in fact, for the most part, not quite empty, but contain as much blood as they are able to admit in their most contracted state. Imbibition by the coats and surrounding tissues will cause a still farther disappearance of the blood. The gradual diminution in diameter which I, as well as Parry and Tiedemann, have observed arteries that have received no injury to undergo during the dissection of a living animal, need be attributed neither to the stimulus of the air, nor generally to the vital contractility of the arteries: it is a necessary consequence of the diminished force of the heart's action under such circumstances.

The arteries are not muscular.—The old writers and many recent physiologists, have erroneously regarded the contraction of the arteries which follows their dilatation as a muscular act, and have looked upon the fibres of the middle arterial coat as muscular fibres. But the fibres of the elastic coat of arteries differ, as we have already mentioned, from muscular fibres both by their physical and chemical properties, as well as by their form, and here the question might be at once dismissed without farther discussion.

The different arguments for the existence of the pretended muscular contractility of arteries, which have been adduced from comparative and pathological anatomy, are of no weight. The dorsal vessel of insects, and the principal, though not all the vascular trunks of the Annelida,—for instance, the leech,—certainly contract by muscular force. But these parts are hearts; for we have already shown that in the lower animals, as in the embryo, the heart is nothing more than a dilated part of the vascular system endued with contractility. The acephalous monsters, also, in which the heart is almost uniformly absent, have been adduced in favour of the muscular contractility of arteries; for in these beings the circulatory system consists of two sets of vessels connected at two different points by a capillary system, namely, in the placenta, and in the organs of the body; but here the heart is merely reduced to the simple tabular form. In many cases, also, the vessels of the acephalous monster are simply branches of the umbilical vessels of a second perfect embryo.[*] The *bulbus aortæ* of fishes and amphibia contracts, it is true, quite distinctly. I have even seen the bulbus aortæ of the frog, when cut away with the aorta, contract as perfectly and distinctly as the heart itself. But this part is quite different from the aorta; it belongs to the heart, and is peculiar to those animals which, during their whole life, or during the first period of it, have a branchial circulation. The aorta of frogs beyond the bulb does not possess a trace of contractility; and Spallanzani,[†] who otherwise contends against the muscular contractility of arteries, is quite wrong when he asserts that the descending aorta of the salamander continues to pulsate when dissected from the body. Dr. Marshall Hall thought he had discovered an artery passing over the great transverse process of the third vertebra in the frog and toad, which continued to pulsate after the heart had been removed. But in this he was mistaken; there is in that situation in frogs a peculiar pulsating lymphatic heart,[‡] which is not, however, connected with an artery, but with a vein. Nor is the oscillating motion of the blood after tying the aorta of the frog, when the blood alternately advances and retrogrades for a short distance, but without regularity, any proof of the muscular contraction of the arteries, although Dr. Marshall Hall adduces it as such. It is entirely the result of the elasticity of the arteries, and of the different mechanical impediments to the course of the blood. The vena cava of fishes close to the heart, possesses muscular contractility, and, according to Nysten,[§] contracts on the application of galvanism; Wedemeyer[‖] also observed this phenomenon both in warm and cold-blooded animals. Their observations are perfectly correct: I have seen the termination of the inferior, and both superior cavæ of the frog, and of the pulmonary veins and cavæ of young warm-blooded animals, contract regularly; the venous trunks of the frog continue to contract even after the removal of the heart and auricle. But the rest of the venous system exhibits no trace of contractility either when under the influence of galvanism or at other times. If Flourens has seen regular contractions of the large veins in the abdomen, they evidently must have been produced by the action of the lymphatic hearts which I have discovered in the frog, and which pump the lymph into the jugular and ischiadic veins. The caudal heart of the eel at the extremity of the caudal vein is contractile, but the vein itself not at all so. The arteries of the thoracic fins of the chimæra, according to Duvernoy, seem likewise to have accessory hearts.

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* Abernethy, Physiol. Lectures, 224.

It has been urged as an argument for the muscularity of arteries, that the pulse sometimes differs in strength in corresponding limbs; for example, in paralysis; but here there are other local causes present to explain the anomaly. In paralysed limbs the reciprocal vital action between the blood and the solids is diminished; they are lax and shrivelled, and often less nourished; while, on the contrary, in active congestion, the increase of the vital processes going on between the blood and the texture of the parts,—the increased organic affinity,—induces a greater flow of blood to the part, and a consequently stronger pulse. In inflamed parts, in which there is accumulation of blood and impeded circulation through the capillaries, the strength of the pulse is increased. But there is no credible authority for the assertion that the pulse ever differs in frequency in different parts, and it is inconceivable how writers in these days can repeat such fables without examining into their accuracy. The rapid expulsion of the blood when an artery is punctured between two ligatures is also merely the result of the elasticity of the coats. Lastly, it has been argued for the muscularity of the arteries, and their active participation in the motion of the blood, that *gangrena senilis* occurs principally where the arteries are ossified. But, as Wedemeyer remarks, this disease sometimes occurs where the arteries are not ossified, and such a state of the arteries does not always produce grangrene, so that gangrena senilis requires other causes for its production; and the old error, "cum hoc, ergo propter hoc" is of no weight.*

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[*] See page 204.
[†] De' fenomeni della circolazione. Modena, 1773.
[‡] See the Section on the Lymph and the Lymphatic Vessels, Chapter ii.
[§] Loc. citat. p. 351.
[‖] Loc. citat. p. 47.

Not merely, however, are all these arguments for the muscularity of arteries without grounds, but there are also counter-arguments to disprove their muscularity. Berzelius justly remarks, that the strongest galvanic and electric stimuli, which produce contractions in all true muscular structures, excite not the slightest motion in arteries. Nysten† repeatedly instituted galvanic experiments on the aorta of criminals just beheaded, but did not perceive the slightest contraction; nor could he excite any contractions in the aorta abdominalis of fishes by means of galvanism. Bichât had previously performed similar experiments with the same results; and Wedemeyer also has endeavoured to produce contractions in the carotids and thoracic aorta of many animals with a galvanic pile of fifty pairs of plates, but has always failed. I have myself made frequent experiments, with the aid of galvanism, to determine this question; and neither in frogs, with feeble or powerful degrees of the galvanic influence, nor in mammalia,—for instance, rabbits,—with a pile of from sixty to eighty pairs of plates, have I been able to produce the slightest trace of contraction of the arteries. It has been remarked by Bichât and Treviranus, that the heart also is insusceptible of the stimulus of galvanism, but that is perfectly erroneous (see page 197).

Mechanical irritation has as little effect as galvanism in producing contraction of the arteries. The application of chemical irritants, such as mineral acids and muriate of lime, certainly gives rise to constriction of the arteries; but it is by producing a chemical change in their texture,—in many cases by extracting a part of the water which they contain;[*] so that this by no means tends to prove their muscularity. The irritability of the muscles in mammalia never endures more than three quarters of an hour after death, while the contraction of the arteries on the application of chemical substances can be produced after the expiration of several days; and other non-muscular parts, such as the skin, are also susceptible of it. Zimmerman[†] observed contractions in fat on the application of sulphuric acid. Tiedemann and Gmelin[‡] observed that sulphuric acid caused arteries to contract which had been preserved a year in spirit. Hot and boiling water also, as Wedemeyer[§] remarks, even on the fourth day after death, produce in the human skin a contraction and wrinkling very similar to muscular contraction; and we can with acids cause similar contractions in muscular fibres which have long lost their irritability, as also in the peritoneum, and the skin. All this proves that most animal tissues, without distinction, whether they possess muscular contractility or not, may, both in the living and in the dead state, exhibit contractility on the application of chemical irritants, from the operation of chemical affinities. These contractions, however, are altogether different from muscular contractions, which can no longer be induced when the parts have lost their vitality, and are excited not merely by chemical, but also distinctly and quickly by mechanical irritants, and by galvanism. Dr. Hastings[‖] was in error when he imagined the contractions produced by chemical agents to be muscular in their nature; and also when he failed to recognise that the true cause of the contraction of the arteries, which follows their dilatation or pulse, is the elasticity of the coats,—the same property which produces in arteries injected with fluid by jerks after death, as well as during life, all the phenomena of the pulse.[¶]

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* On all this subject consult Wedemeyer, loc. cit.

† Recherches de Physiol. et Pathol. chimiques. Paris, 1811.

Insensible vital contractility of arteries.—From all these facts it results that the circulation is in no way dependent on periodic muscular contractions of the arteries; and that the diminution of diameter of the arteries after their extension by the impulse of the blood forced into them, is an effect of their elasticity alone. But, whether the narrowing of arteries observed in arresting hemorrhage from them, in exposing them to the air, and in the operation of torsion, is wholly an effect of elasticity, or whether, in addition to this, they possess the vital property of gradual, not periodic, contraction—*tonus*,—admitted by Parry, Weber, and Tiedemann, and by the last-named physiologist believed to exist also in the trunks of the lymphatics,—is quite a different question. Several observers had seen a slow contraction of the small arteries follow the application of cold; and the experiments of Schwann, by the application of cold water to the mesentery of the frog and rana bombina, demonstrate it most clearly. After having extended the mesentery under the microscope, he placed upon it a few drops of water, the temperature of which was some degrees lower than that of the atmosphere. The contraction of the vessels soon commenced, and gradually increased, until, at the expiration of ten or fifteen minutes, the diameter of the canal of an artery in the mesentery of a toad, which at first was 0·0724 of an English line, was reduced to 0·0276. The diameter, therefore, was reduced to ½ or ⅓; and the area, consequently, to ¼ or ⅑ of its previous dimensions. The arteries then dilated again, and at the expiration of half an hour had acquired nearly their original size. By renewing the application of the water the contraction was reproduced; in this way the experiment could be performed several times on the same artery. The veins did not contract. I have frequently observed this phenomenon as Schwann has described it. Hastings and Williams have made similar observations. It is not known on what tissue this kind of contractility depends: it is certainly not due to muscular fibres, for they do not exist in arteries. By the aid of high magnifying glass, delicate and not very distinct transverse fibres can be distinguished in the parietes of the smallest arteries of the mesentery of the frog; and Dr. Schwann has discovered that even the capillary vessels in the mesentery of the frog have similar fibres—a fact which decides the question as to capillaries having distinct parietes. The power of cold to excite contraction in them, and the inefficiency of electricity to produce that effect, are characteristic of many parts which are not muscular. In both these characters the contractile tissue of arteries resembles the contractile tissue of the tunica dartos, which yields gelatin in boiling, and which in its microscopic characters resembles the cellular tissue, and by no means the ordinary elastic tissue.* The slow narrowing of divided arteries, their retraction into their sheath of cellular tissue, and the coagulation of the blood, account for the spontaneous cessation of hemorrhage from arteries which are not of very large size. The vital property of tonicity, or insensible contractility, will, as Dr. Parry pointed out, very well explain the partially empty state of the arteries after death; for the arteries, after a certain time, must lose the vital power of gradual contraction by which they had expelled their blood, and would again dilate, retaining merely their physical endowment of elasticity, which is not lost until decomposition takes place. Dr. Parry states that he has observed these changes in the diameter of the arteries after death.

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[*] See Hildebrandt, Anat. t. iii.

[†] De irritabilitate. Gött. 1751.

[‡] Versuche über die Wege, &c. 68.

[§] Loc. cit. p. 75.

[‖] On Inflammation of the Mucous Membranes. London, 1829. Translated into the German by Busch. Bremen, 1822.

[¶] See also the remarks of Dr. Parry on the arterial pulse. Bath, 1816. Translated into the German. Hanover, 1817.

Force and rate of the blood's motion in the arteries.—The above inquiry places it beyond a doubt, that the only power by which the blood is moved in the arteries, is the force of the heart's contraction. We have now to determine the degree of force thus exerted by the heart, and the force and rapidity of the blood's motion in different parts of the arterial system. Hales* was the first who made any observations on the height to which the blood rises in glass tubes introduced into different vessels: he observed that from the crural artery of the horse it rose 8 or 9 feet: from the temporal artery of the sheep, 6½; from the carotid artery of the dog, 4 to 6 feet; while from the jugular vein of the horse it rose only from 12 to 21 inches; in the sheep, 5½ inches; in dogs, from 4 to 8½ inches. We shall, however, on this subject have recourse chiefly to the accurate researches of M. Poiseuille.† M. Poiseuille made use of an instrument which he invented for the purpose. It was a long glass tube, bent so as to have a short horizontal portion, a branch descending at right angles from it, and a long ascending branch. Mercury poured into ascending and descending portions, will necessarily have the same level in both branches, and in a perpendicular position the height of its column must be the same in both. If now the blood is made to flow from an artery through the horizontal portion of the tube into the descending branch, it will exert on the mercury a pressure equal to the force with which it is moved in the arteries, and the mercury will, in consequence, descend in this branch, and ascend in the other. The depth to which it sinks in the one branch, added to the height to which it rises in the other, will give the whole height of the column of mercury which balances the pressure exerted by the blood; the weight of the blood which takes the place of the mercury in the descending branch, and which is more than ten times less than the same quantity of quicksilver, being subtracted. M. Poiseuille calculated the force with which the blood moves in an artery according to the laws of hydrostatics, from the diameter of the artery, and the height of the column of quicksilver; that is to say, from the weight of a column of mercury whose base is a circle of the same diameter as the artery, and whose height is equal to the difference in the level of the mercury in the two branches of the instrument. To prevent the coagulation of the blood in the horizontal part of the tube, it was filled with a solution of carbonate of potash. According to Poiseuille, the force of the blood's motion in the larger arteries, for instance, in the carotid and crural arteries, and in the carotid and aorta, is equal; difference in size, and distance from the heart, being unattended by any corresponding difference of force in the circulation. The height of the column of mercury displaced by the blood was the same in all the arteries of the same animal. Poiseuille finds that the force of the blood in any large artery will in a dog support a column of mercury of 151 millim. [about 6 English inches], or a column of water of 6⅓ French feet [about 6 feet 10½ inches English]; in mares, a column of mercury of 161 millim. [6 inches 4 lines, English], or a column of water of 6 feet 9 inches [7 feet 3 inches, English]; in horses, a column of mercury of 159 millim. [6 inches 3 lines, English]; and, calculating from the former two animals, in the mean a column of mercury of 156 millim., 6 inches 1½ lines, English, or a column of water of 6 feet 7 inches, 7 feet 1 inch, English.*

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* See Book I. chap. 1. page 115.

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* Statical Essays. Translated into the German. Halle, 1748.

† Magendie's Journal, viii. 272.

Poiseuille concluded from his experiments, which seemed to prove that the force with which the blood is moved, is the same in the most different arteries, that to measure the amount of the blood's pressure in any artery of which the calibre is known, it is necessary merely to multiply the area of the vessel by the height of the column of mercury which is already known to be supported by the force of the blood in any part of the arterial system. The weight of a column of mercury of the dimensions thus found will represent the pressure exerted by the column of blood. For example, Poiseuille estimates the diameter of the aorta at its origin, in a man of twenty-nine years, at 34 millimeters. Its area will therefore be 908·2857 square millimeters. Assuming now that the mean of the greatest and least height of the column of mercury found by experiments on different animals to be supported by the force of the blood, is equivalent to the height of the column which the force of the blood in the human aorta would support, we shall have the mean of 180 and 140 millimeters—consequently 160 millimeters—as the height of this column: 160 millimeters, then, multiplied by 908·2857 = 145325·71 cubic millimeters, will be the amount of mercury in the column, and the weight of this quantity of mercury—namely, 1·971779 kilogrammes, or 4 lbs. 3 drs. 43 grs., about 4 lbs. 4 oz. avoirdupois—will indicate the static force with which the blood is impelled into the aorta. By the same calculation, the force of the circulation in the aorta of the mare is found to be 10 lbs. 10 oz. 7 drs. 61 grs. [about 11 lbs. 9 oz. avoirdupois]; in the radial artery, 4 drs.

Influence of respiration on the motion of the blood in the arteries.—Poiseuille perceived, by means of his instrument, what Haller and Magendie had already observed, namely, that the strength of the blood's impulse is increased during expiration; in which act the chest is contracted, and the large vessels in consequence compressed. The column of mercury in his instrument rose somewhat at each expiration, and fell during inspiration. The extent of the rise and fall of the mercury was the same in arteries, the distance of which from the heart was different, and in ordinary tranquil respiration amounted to from four to ten lines. The increase of the blood's impulse by expiration is in many persons so great, that the pulse at the radial artery becomes imperceptible when inspiration is long continued, and the breath held. This is the case with myself, and it in some measure explains the fable of persons possessing the power of altering the action of their hearts at will.

Effect of anastomoses on the motion of the blood in the arteries.—It was formerly believed that the angles at which the branches of

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* These numbers, if intended as the mean of the results given in M. Poiseuille's table, ought to be,

For the dog, - a column of mercury of	155·44 millim.
For the mare, - - - - - - -	164·36 —
For the horse, - - - - - - -	152·86 —
And the mean of the three will be, - -	157·55 —

vessels are given off, according as they are obtuse or acute, influence the rapidity of the blood's motion; the obtuse angle being supposed to retard it. But Weber* remarks that this circumstance influences the rapidity of the motion of a fluid only when it meets with so little resistance in its progress, that the sum of the impulses which propel it can give a determinate direction to its course; but that, when the resistance it experiences is so great that each fresh impulse is lost in overcoming it, the angles at which the branches of the tubes are given off no longer have this effect. The fluid in the tubes in this case is everywhere exposed to the same pressure, and itself tends with equal force in all directions. The reason that the blood flows more slowly in the capillaries than in the larger vessels is, that the aggregate capacity of the small vessels is greater than that of the vessels from which they arise. The causes which tend to diminish the rapidity of the circulation generally are, not so much the frequent anastomoses of the arteries, as the constantly increasing friction between the blood and the parietes in the small vessels. Anastomoses facilitate the distribution of the blood. When two arteries anastomose, branches may arise from the anastomosing vessels, or from the communicating branch itself. In the former case, the communicating branch, as far as can be observed with the microscope, is traversed in the direction which offers the least resistance, and the blood is conveyed into that vessel, the capacity of which is great enough to receive the blood of two vessels at the same time. In such cases, however, the anastomosis is traversed always in one direction. If the anastomosis itself gives off a branch, the blood flows either from two sides at the same time into this branch, or in one direction only. During life, the direction in which the blood flows in anastomoses must vary very much, according as accidental pressure affects the part.

OF THE CAPILLARIES.

1. *Structure of the Capillaries.*

Definition of the term "capillaries."—In all organic textures the transmission of the blood from the minute branches of the arteries to the minute veins is effected by a network of miscroscopic vessels, in the meshes of which the proper substance of the tissue lies. This may be seen in all minutely injected preparations; and, during life, by the aid of the microscope, in any transparent parts,—such as the web of the frog's foot, the lungs and urinary bladder of the frog, the tail of the tadpole, the incubated egg, young fishes, the gills of the larva of the salamander, the wings of the bat, and the mesentery of all Vertebrata,—and, as I have pointed out,† even in some opaque textures of the larva of the salamander by means of a simple microscope. The ramifications of the minute arteries form repeated anastomoses with each other, and these anastomoses terminate at last in a continuous network, from which the venous radicles, on the other hand, take their rise. The reticulated vessels, connecting the arteries and veins, are, on account of their minute size, vessels, called capillary vessels. The point at which the arteries terminate and the minute veins commence cannot be exactly defined, for the transition is gradual; but the intermediate network has, nevertheless, this peculiarity, that the small vessels which compose it maintain the same diameter throughout: they do not diminish in diameter in one direction, like arteries and veins. This, however, does not justify us in admitting with Bichât, that the capillaries are a peculiar system of vessels.

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* Hildebrandt's Anat. B. iii. p. 41.

† Meckel's Archiv. 1829.

The size of the capillary vessels is proportioned to that of the red particles of the blood, and can be measured in parts finely injected. Their diameter varies from $\frac{1}{1800}$th to $\frac{1}{4000}$th, even to $\frac{1}{5000}$th of an inch, but in the mean is most frequently between $\frac{1}{3700}$th and $\frac{1}{1850}$th of an inch.

Table of the size of the capillaries in different injected parts.

Organ.	*Observer.*	*Diameter in fractions of an English inch.*
In the brain - -	E. H. Weber	$\frac{1}{4700}$
Human Kidney - -	Müller - -	from $\frac{1}{2300}$ to $\frac{1}{1582}$
Ciliary processes -	Do. - - -	$\frac{1}{1754}$
Mucous membrane of large intestines	Weber - -	from $\frac{1}{2794}$ to $\frac{1}{1851}$
Lymphatic gland -	Do. - - -	$\frac{1}{2754}$ to $\frac{1}{1851}$
Skin - -	Do. - - - -	$\frac{1}{1149}$
Inflamed membrane -	Do. - -	from $\frac{1}{3848}$ to $\frac{1}{1932}$

The capillaries in their natural state, when filled with blood, and when they are not so much distended as when injected, have been seldom measured. In the scrotum of a new-born child, where the cuticle could be removed, Weber found their diameter to be $\frac{1}{3518}$th of an inch. In very young animals the capillary vessels are larger than in the adult, thus corresponding in size to the red particles of the blood, which are also in part larger at the former period. No other elementary tissues are much more minute than the capillaries. The muscular fibres, the minuteness of which has hitherto been much overrated, measure, according to Prevost and Dumas, $\frac{1}{7477}$th of an inch in diameter. The primitive fibrils of the muscles of man are five or six times smaller than the red particles of his blood. The primitive nervous fibril in Mammalia, according to my measurement, is from one-third to one-half the size of the red particles of the blood.

No other tubes in the body are so minute as the capillary vessels. The diameter of the biliary ducts of the liver and of the tubuli uriniferi, even where they are the finest, is several times greater than that of the capillary vessels. All these different elementary tissues, glandular ducts, muscular fibres, and nervous fibrils, are surrounded and connected together by a network of capillaries. The primitive fibres of muscles, and those of the nerves, are not themselves traversed by any blood-vessels; for they are smaller than the finest capillaries. In examining recent and well-injected specimens of these parts, no other capillary vessels are seen than those which are distributed in the interstices of the primitive fibres, and it is the same with regard to the minute ducts of glands. The capillary vessels of the kidneys run everywhere in the interstices and on the surface of the urinary ducts; but the ducts themselves, according to my observations, contain no blood-vessels.

The form of the capillary network is in general very uniform, and varies merely in the size of the meshes, or in their being elongated or not. In the capillary network of muscles and nerves, the meshes are elongated in the direction of the primitive fibrils on which they are distributed. The remarks of Soemmering and Doellinger, and especially those of Berres,* with regard to the variety in the distribution of the minute vessels in the different tissues, are very correct; they do not, however, refer to the capillary vessels themselves, but to the minute arteries and veins which ramify and divide still farther, before forming the capillary network. Soemmering observes, that the mode of ramification, in the small intestines resembles a tree which is not in leaf, in the placenta a tuft, in the spleen an asperge or sprinkling-brush, in the muscles a branch of twigs, in the tongue a hair-pencil, in the liver a star, in the testicle and in the choroid plexus of the brain a lock of hair, in the Schneiderian membrane a trellis-work. In the branchiæ the arteries and veins take the direction of the branchial lamellæ, the arterial current ascending on one side, the venous descending on the other. The form of ramification of the vessels of tendons, which are not immediately connected with the long twig-like vessels of the muscles, is, according to E. H. Weber, dendritic. It appears, however, that the vessels spoken of by Prof. Weber are merely those of the sheath of the tendon; the true vessels of tendons, as recently described by Mr. Paget, run longitudinally in straight parallel lines, rarely give off branches, and rarely anastomose, though occasionally a transverse twig passes from one longitudinal vessel to another; each artery is accompanied by a single vein.† In the cortical portion of the kidneys there are peculiar *glomeruli* of blood-vessels in the midst of the capillary network.‡ Huschke has very recently proved that the minute artery which enters one of these vascular ganglia, issues from it again, after making several convolutions, and then becomes continuous with the capillary network.§ This may be seen distinctly in the triton or water salamander. At the extremity of each of the villi which form the tufts of the human placenta, a minute artery becomes directly continuous with the minute returning vein. Thus the mode of division of the minute arteries presents many varieties, while the capillary network itself differs merely in the size of the meshes, and in their more oblong or equilateral figure. Of this I have been convinced in the course of my researches on the glands; for in these organs, however various the distribution of the minute ducts may be, the capillary vessels have always the simple reticulated form, and do not follow in their arrangement the distribution of the ducts. In the medullary portion of the kidneys, where the urinary tubuli are collected into pyramidal bundles, the small arteries, and, as I have recently more than once satisfied myself by injection, the veins also, run in the form of long straight vessels between the urinary ducts, and have commonly been mistaken for ducts injected from the blood-vessels; but even these straight blood-vessels give off capillaries which form elongated meshes, and, diminishing in size as they run from the cortical portion towards the mammella, terminate at last on the mammella itself, in a fine network surrounding the openings of the urinary ducts. In the same way the smaller branches of the blood-vessels run lengthwise between the muscular and nervous fibrils; but the true capillary vessels form a network around the parallel fibres of the muscles and nerves, just as they do in the testicle around the convoluted *tubuli seminiferi*, and in the cortical portion of the kidney around the *tubuli uriniferi*. The small arteries in the branchiæ of the salamander also follow the mode of division of the branchial lamellæ, and terminate at the extremity of each lamella in descending branchial veins; but between the two vessels there is, even in the smallest lamella, a network which Rusconi and others have overlooked, but in which I have seen the red particles of the blood circulating.

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* Med. Jahrb. d. Österr. Staates. Bd. 14.

† See Med. Gazette, July 13, 1839.

‡ See the Section on Secretion, Chapter ii. and my work De Gland. Struct. penit. pp. 100, 101.

§ Tiedemann und Treviranus, Zeitschrift für Physiol. 4 Bd. 1 H. p. 116, tab. vi. fig. 8.

Number of the capillaries and size of the meshes in different parts.—The parts in which the network of capillaries is closest, that is, in which the meshes are the smallest, are the lungs and the choroid membrane of the eye. In the iris and ciliary body, even, the interspaces are somewhat wider. The vascular network is also very close in the mucous membranes of the lungs, liver, and kidneys, and in the cutis vera. In the choroid of the turkey, the interspaces are of the same size, or even smaller than the capillary vessels themselves. In the human lung the interspaces are, if anything, smaller than the vessels which form the network. In the human kidney, and in the kidney of the dog, the diameter of the injected capillaries, compared with that of the interspaces, is in the proportion of one to four, or of one to three. The brain receives a very large quantity of blood; but the capillaries in which the blood is distributed through its substance are very minute, and less numerous than in some other parts, so that the blood must pass through it into the veins more quickly than in other organs. E. H. Weber found the diameter of the capillaries in the brain, compared with the long diameter of the meshes, in the proportion of one to eight or ten; compared with the transverse diameter, in the proportion of one to four or six. In the mucous membranes—for example, in the conjunctiva—and in the cutis vera, the same observer found the capillary vessels themselves much larger than in the brain, and the interspaces narrower,—namely, not more than three or four times wider than the vessels. In the periosteum the meshes were much larger.* The bones, cartilages, ligaments, and tendons are the parts which have the smallest number of blood-vessels and capillaries. At the line limiting muscle and tendon, the great difference in the vascularity of the two parts is very observable; the greater number of the blood-vessels of the muscles are, according to Doellinger, reflected back again, and have no immediate connection with the scanty vessels of the tendons. Prochaska† observed the same relation between the free portion of the synovial membrane and that which covers the articular cartilages. I saw very beautiful injected preparations of the cartilages of the trachea, larynx, and costal cartilages of a fox in the museum of Fremery at Utrecht. The existence of vessels in the internal shining layer of the serous membranes, has hitherto been doubtful; but some injections of the peritoneum by Bleuland, which I saw at Utrecht, made me hesitate to adopt Rudolphi's opinion, that the vessels of serous membranes are situated in the subserous cellular tissue; and Schroeder van der Kolk‡ has injections of the peritoneum, which prove indubitably that this membrane contains vessels. It is still doubtful whether the vitreous humour and the substance of the cornea are supplied with capillaries.

Have the minute arteries open mouths?—Microscopic observations and minute injections have shown that the capillary vessels are merely the fine tubes which form the medium of transition from arteries to veins, and that no other kind of vessel arises from them; that the minute arteries have no other mode of termination than the communication with the veins by means of the capillaries; in a word, that there are no vessels terminating by open extremities. It is the more necessary to demonstrate this fact, which minute anatomy has clearly shown, since Haller unfortunately adopted, and thus contributed to confirm, the crude notions of his predecessors regarding the open terminations of arteries. He admitted that arteries terminate in five ways: 1st, by openings on the surface of membranes; 2d, in lymphatics; 3d, in secreting canals; 4th, in fat; and, lastly, in veins. But in those times the secretion of mucus and fat could not be understood, without presupposing the existence of open extremities of the blood-vessels. After Mascagni, Hunter, Prochaska, and Soemmering had contended with success against this hypothesis of the open termination of arteries, it still remained a matter of doubt whether there was not a communication between the blood-vessels and the secreting canals of the glands. My researches, however, on the structure of all glands, in which better auxiliary means have been had recourse to, such as the injection of the secreting canals themselves, the use of the microscope, and the history of the development of the embryo, together with similar observations by Huschke and Weber, have proved that no such communications exist in any secreting gland, and that the radicles of the secreting canals, however various their form in the different glands, are always closed at their radicle extremity. The existence of exhalent vessels also, which even Bichât admitted, and supposed to be open side-branches of the capillary vessels, is purely hypothetical. An exhaling membrane, such as the peritoneum, has merely reticulated capillary vessels spread out over a great superficies, and the fluids are exhaled into the cavities by permeating the substance of the membrane itself: all animal textures being permeable by fluids, by virtue of the pores which, though not visible, must necessarily exist even in the smallest molecules of the animal substance that are capable of being softened by fluids. It is owing to this porosity that when arteries are injected with a solution of size coloured with cinnabar, a colourless fluid, as was pointed out by Mascagni, exudes on the surface of the membranes, the colouring particles not being able to pass through the pores.

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* Weber in Hildebrandt's Anat. 3 Bd. p. 45.

† Disquisitio anatomico-physiologica Organismi humani. Viennæ, 1812, p. 96.

‡ Observ. anat. path. 27.

Serous vessels, that is, branches of the blood-vessels too minute to allow the passage of the red particles, and consequently traversed merely by the lymph of the blood, may possibly exist, though they have not been demonstrated. In favour of this hypothesis those parts are adduced in which no vessels carrying red blood have hitherto been discovered, namely, the cornea, the capsule of the crystalline lens, and the vitreous body.

The existence of vessels in the substance of the cornea is doubtful; they have never been injected. Nevertheless, penetrating ulcers and granulations are formed in the cornea, which can scarcely be conceived to occur without the agency of vessels. In calves of nearly the full time, I have repeatedly seen vessels containing red blood in the corneal conjunctiva, and could not trace them with a lens more than a line over the margin of the cornea. Henle has injected and made drawings of these vessels; they measured from $\frac{1}{1349}$th to $\frac{1}{664}$th of an inch, and the finest twigs were not then injected; their trunks, which arose from a circular vessel that ran around the cornea, were somewhat larger. I have the preparations of these parts in my possession. Professor Wutzer has seen them. Professor Retzius has injected similar vessels in adult animals.* It is well known that in inflammation the cornea contains vessels carrying red blood. I saw at Utrecht, in the possession of Schroeder van der Kolk, a most beautiful injected preparation of a slightly inflamed eye, in which the conjunctiva as well as the aqueous membrane were injected. The posterior capsule of the lens even in full-grown animals contains vessels carrying red blood, derived from the branch of the *arteria centralis*, which traverses the vitreous humour to reach the posterior capsule. I have seen these vessels sometimes filled with blood in the fresh eyes of the calf and ox; Zinn saw the same thing. Henle has shown that the vessels of the posterior capsule in the fœtus communicate with vessels of the *zonula Zinni* or *corona ciliaris*, and ciliary processes; and he has injected and given a representation of the communicating branches. In the embryo of Mammalia the vessels of the posterior capsule are connected with those of the pupillary membrane through the medium of a very vascular membrane, which I have discovered,—the membrana capsulo-pupillaris. This new membrane is stretched between the inner border of the iris and the inner border of the corona ciliaris, or the border of the capsule of the lens, and contains numerous parallel longitudinal vessels, which pass from the iris and pupillary membrane to the *corona ciliaris* and posterior capsule of the lens. In the anterior capsule the vessels are extremely difficult to demonstrate; but in inflamed eyes they are distinct both on the anterior and posterior wall of the capsule, as I saw in an excellent injected preparation of a cataractous eye in Schroeder van der Kolk's collection at Utrecht. The *zonula Zinni*, or *corona ciliaris*, appears, from Henle's and Schroeder's injections, to be a vascular organ, and to be of great importance for the nourishment of the transparent humours. The vitreous body contains blood-vessels, at all events in the embryo and in fishes.

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* See Henle, De Membrana pupillari aliisque Membranis Oculi pellucentibus. Bonnæ, 1832.

All these facts, however, render it very probable that even the cornea and capsule of the lens, to which vasa serosa have been hitherto ascribed, are really provided with vessels carrying red blood; and it is certain that the capsule of the lens of the eye of the ox, as well as the corneal conjunctiva in the fully developed fœtus of the sheep, are supplied with red blood. The vessels of the corneal conjunctiva are certainly infinitely less numerous than those of the sclerotic conjunctiva; there is the same difference between those two parts as between the part of the synovial membrane which is free, and that which covers the articular cartilages. E. H. Weber remarks, very correctly, that a single stratum of capillary vessels is not at all recognisable by the eye alone; the colourless appearance of the parts of which we have been speaking, consequently, does not prove that they contain no blood-vessels. The mesentery, also, in the space between the large vessels appears to the naked eye to be equally free from vessels, and transparent; but by the aid of the microscope numerous capillaries become evident in it.* While, however, we maintain that blood-vessels exist even in transparent membranes, we by no means prove that all the vessels of these parts are of such size as to admit the red particles of the blood. On the contrary, it is probable that the greater part of the more delicate vessels of these parts transmit only the fluid part of the blood, the *liquor sanguinis;* and in other parts also there may be such minute capillaries conveying merely the *liquor sanguinis* from the arteries to the veins. It would be wrong, however, to distinguish these vessels from the rest of the capillary system, as vasa serosa, since they are not essentially different from other capillaries, and since the same vessels which ordinarily carry merely the fluid of the blood, are often traversed from time to time by single red particles. The question concerning the existence of serous vessels has now lost much of its interest, since we know that such vessels are not necessary either for the nutrition or growth of tissues.—See Book I, chapter I.

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* On this subject generally, consult Henle, loc. citat.

Have the capillaries membranous parietes?—The question whether the minute capillaries have membranous parietes is important. It has been the universal testimony of observers, from Malpighi to Doellinger, that in living animals no membranous walls are discoverable by the aid of the microscope. Doellinger* regards the blood as fluid animal substance, the substance of the organs as solid blood. Gruithuisen saw the blood flowing in free spaces between the acini of the liver in the frog: this is seen, according to my experience, much more distinctly in the liver of the larva of the triton, which alone I found adapted for the observation.† Wedemeyer doubted the existence of membranous parietes, from observing the broad currents of blood and the small islets of solid tissue in the lungs of the salamander. C. F. Wolff, Hunter, Doellinger, Gruithuisen, Baumgärtner, Wedemeyer, Meyen, and Oesterreicher also deny the existence of membranous parietes to the capillary vessels; while Leeuwenhoeck, Haller, Spallanzani, Prochaska, Bichât, Berres, and Rudolphi are of the contrary opinion.

The argument for the non-existence of membranous tubes, which Doellinger and Oesterreicher deduce from the development of new vessels, cannot be applied to vessels already formed; and more accurate researches appear, indeed, to refute altogether the hypothesis of the circulation of the blood in canals without membranous tubes. The facts that fluids injected into the arteries pass into the veins without extravasation, and that currents cross above and below each other without uniting, have been adduced as arguments for the existence of membranous parietes to the capillaries. The number of the currents, and indeed the smallness of the islets of solid matter between them in the pulmonary membrane of the frog and salamander also tend to prove that membranous tubes must exist; for otherwise these small islets would themselves be sometimes involved in the currents. But there are also direct means of proving the existence of membranous tubes around the capillary streams. For this purpose we must select a very delicate parenchyma, which easily softens and dissolves in water, so as to leave behind the network of capillaries. In a piece of the cortical substance of the kidney of a squirrel which had been laid in water for a short time only, but long enough to have become softened, the capillary vessels which are interlaced around the tubuli uriniferi appeared to me, when I examined them by the microscope, to be independent parts. In the choroid, iris, and ciliary processes, the capillaries are still more evidently substantial independent parts. They can, however, be demonstrated most distinctly in the plicated organ discovered by Treviranus in the cochlea of the internal ear of birds. C. Windischmann‡ concludes, from his dissections, that the laminæ of this part are merely folds and wrinkles of a membrane which arches over the spiral plate of the cochlea. The membrane is extremely delicate and pulpy; its soft substance is however traversed by an extremely beautiful network of vessels, which Windischmann has injected from the carotid; it dissolves easily in water, leaving the beautiful vascular network with the meshes empty.* In the uninjected state, also, the vascular network remains after the pulpy substance has been dissolved. Lastly, Schwann has recently ascertained, by means of the microscope, that the capillaries have not merely membranous parietes, but a coat in which circular fibres arranged as in the arteries can be distinguished. This he discovered in the capillaries of the mesentery of the frog, and brown or fire toad (Rana bombina). It is necessary to employ a high magnifying power and rather a feeble light; but the fibres may be seen in the dead, as well as in the living animal. But even where no transverse fibres are visible, the capillaries seem to have delicate membranous parietes, in the substance of which oval bodies resembling nuclei of epithelium scales appear at intervals. This structure of the capillaries has been observed by Henle in the cerebral substance, and by Schwann in the tail of tadpoles, and has been distinctly seen by the translator in the tail and branchiæ of the larva of the salamander, in the web of the frog's foot, and in the substance of the kidney.

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* Denkschriften der Akad. zu Müchen, 7.

† See Meckel's Archiv. 1829.

‡ De penitiori Auris Structurâ in amphibiis, cum tab. iii. Bonnæ, 1831. Lips. apud Voss.

2. *Circulation in the Capillaries.*

As viewed by the microscope.—If the circulation in any transparent part of a living adult animal is examined by means of the microscope, the blood is seen to flow through the minute arteries and capillaries with a constant equable motion. In very young animals the motion, though continuous, is accelerated at intervals corresponding to the pulse in the larger arteries, and a similar motion of the blood is also seen in the capillaries of adult animals when they are feeble: if their exhaustion is so great that the power of the heart is still more diminished, the red particles are observed to have merely the periodic motion, and to remain stationary in the intervals; while, if the debility of the animal is extreme, they even recede somewhat after each impulse. These observations of Wedemeyer, which I must confirm as the result of all my experiments, are of great importance; for they prove that, even in the state of the greatest debility, the action of the heart is sufficient to impel the blood through the capillary vessels. The pulsatory motion of the blood in the capillaries cannot be attributed to an action in these vessels themselves; for when the animal is tranquil, they present not the slightest change in their diameter.

It might be supposed that, even in the natural state, the blood flows in this pulsatory manner through the capillaries, and that the apparent regularity of its motion is attributable to the rapidity of the circulation, which, when viewed by the microscope, appears even greater than it really is; but the fact that the blood flows in an equable stream from the veins, proves that the effect of the impulses communicated to the blood is, in the natural condition, really lost in the capillary system.

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* See Windischmann, loc. cit. tab. ii.

The cause of the equable motion of the blood in the capillaries must be sought in the elasticity of the arteries. The elastic coat of the artery is, during each pulsation, distended by the blood forced into it, but during the intervals of the heart's action contracts again, so as to force on the blood, and convert its merely periodic motion into a continuous although periodically accelerated one; and thus by the time that the blood reaches the minute arteries, the impulse given by each contraction of the ventricle is lost in dilating the arteries, while the continuous motion—the result of their elasticity—remains. During its course through the small vessels, the circulation of the blood will necessarily be modified by the unequal obstructions that it meets with, causing it to be checked for a time in one vessel, while it circulates more quickly through others; but the pulsatory motion will no longer be perceptible. When an animal, however, is much weakened, and the propulsive power of the heart consequently diminished, the arteries become distended by less blood at each pulsation, and in their turn react with less force upon the blood. The cause, therefore, which in the natural state renders continuous the periodic motion of the blood, is not under these circumstances brought into action, and the blood moves forward only at the time of each beat of the heart, the effect of which is then perceptible in the capillaries. The oscillating motion of the blood in debilitated animals is said by Koch* to be independent of the heart's action. To both Wedemeyer and myself, however, it appeared to be wholly dependent on the contraction of the heart being too feeble to overcome the resistance offered by the capillaries; so that some part of the blood, in the intervals of the contractions, receded again, notwithstanding the presence of the valves.

The degree of resistance which the capillaries offer can be calculated from the results of the experiments instituted with that view by Hales and Keill. The mode which Keill adopted was, to compare the quantities of blood which flowed in a given time from the divided crural artery and from the crural vein of a living dog. The quantity derived from the crural artery compared with that from the vein, was in the proportion of 7½ to 3, so that from these data the resistance to be overcome in the capillaries would seem to neutralise $\frac{9}{15}$ths or $\frac{3}{5}$ths of the force with which the arterial blood moves.

Hales† injected the mesenteric artery of a dead animal with water, by allowing a column of that fluid 4½ feet high to press into the artery, having previously divided the intestines along the line opposite to the insertion of the mesentery. The quantity of water which flowed from the divided capillaries, amounted to one-third only of the quantity which escaped in the same time when the larger branches of the artery were divided; so that according to this experiment, the resistance offered by the capillaries equalled two-thirds of the force with which the water was forced into them.

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* Meckel's Archiv. für Anat. und Physiol. 6 Bd. p. 216.

† Statical Essays.

Rate of the capillary circulation.—To make a comparison of the rate of the circulation in the capillaries and arteries, we must take the mean rapidity of the blood's motion in these vessels at different times and in different situations; for in the arteries the velocity of the circulation is greater at the moment of the pulse than in the intervals of this act, and in the capillary system it is seen by the microscope to vary very much in different capillary vessels.

If the sectional area of all the branches of a vessel united were always the same as that of the vessel from which they arise, and if the aggregate sectional area of the capillary system were equal to that of the aorta, or, in other words, if the aggregate capacity of the tubes through which the blood passes were the same in all the degrees of their ramification,—the mean rapidity of the blood's motion in the capillaries would be the same as in the largest arteries; and, supposing a similar correspondence of capacity to exist in the veins and arteries, there would be an equal correspondence in the rapidity of the circulation in them. It is quite true that the force with which the blood is propelled in the arteries, as shown by the quantity of blood which escapes from them in a certain space of time, is much greater than that with which it moves in the veins; but this force has to overcome all the resistance offered in the arterial and capillary system,—the heart itself, indeed, must overcome this resistance: so that the excess of the force of the blood's motion in the arteries, is expended in overcoming this resistance, and the rapidity of the circulation in the arteries, even from the commencement of the aorta, would be the same as in the veins and capillaries, if the aggregate capacity of the three systems of vessels were the same.

But since the aggregate sectional area of the branches is always greater than that of the trunk from which they arise, the rapidity of the blood's motion will necessarily be greater in the trunk, and will diminish in proportion as the aggregate capacity of the vessels increases during their ramification.

The motion of the blood in the capillaries is wholly dependent on the heart's action. Many physiologists, believing that the power of the heart is not sufficient to propel the blood through the capillary system, have imagined the existence of other auxiliary forces, such as contractions of the capillaries themselves, or a spontaneous motion of the blood,—neither of which, however, has been demonstrated by direct observation. On the contrary, it is irrefragably proved, that the motion of the blood through the capillaries is effected solely by the action of the heart; for in animals, the strength of which is much exhausted, the impulse communicated to the blood by the ventricles is visible in the capillaries; and the flow of blood from a divided vein is accelerated during expiration, proving that the increased impulse given to the current of blood by the compression of the great vessels in the chest, is also transmitted through the capillaries to the veins. The dependence of the circulation of the blood in the veins on the action of the heart, is also proved by the following experiment of Magendie:—He applied a ligature to the leg of a dog, the crural artery and vein not being included. The vein was then tied separately, when it was seen to become turgid below the ligature, with the blood returning from the limb; and, if it was punctured at that part, the blood spirted out in a full stream. When the crural artery was compressed, the flow of the blood from the vein gradually ceased, but recommenced when the pressure on the artery was remitted. Poiseuille, by means of the instrument already described, measured the pressure of the blood in the portion of a vein most distant from the heart, and found it to be exactly proportioned to that of the blood in the arteries, increasing and diminishing according as the force of the blood in the latter vessels was greater or less.*

The differences of the blood's motion in different capillaries arise from mechanical causes. Wedemeyer's description of the course of the blood in the anastomosing capillaries, agrees perfectly with what I have observed. Sometimes, he says, the red particles flow rapidly from one current into a second, as if by attraction. In other cases the second current being very rapid, the red particles seem to be arrested in the collateral current, and only from time to time find means of entering the rapid stream. Sometimes a red particle is even thrown back for a moment out of the more rapid into the weaker current, but being repelled, resumes its former course.

I have also remarked, that the same anastomosing branch between two currents sometimes receives the blood in one direction, and sometimes in the other, and that variations of pressure and position, and motions of the animal, are always the causes of these changes. All these variations in the capillary currents are then, just as in currents of water on irrigated land, merely the results of mechanical causes. In the most minute capillaries, which are not red, nor even yellow, but quite transparent, there is merely a single line of red particles separated by unequal intervals; and from time to time no red particles are seen in these colourless vessels; but I have observed no canals through which red particles did not occasionally pass, and which, therefore, could deserve the name of *vasa serosa;* and Wedemeyer, who says that he has seen such *vasa serosa*, himself confesses that some of the red bodies traversed them from time to time. The red particles do not rotate on their own axes while passing through the capillaries; in the frog they appear, for the most part, to move with the long diameter in the axis of the vessel; but frequently they are placed obliquely, and their position suffers many changes from the mechanical influence of the coats of the vessels; the red particles themselves are quite passive, and never present the slightest sign of spontaneous motion. Several observers have remarked that, in passing through a narrow portion of the vessel, the red particles are sometimes compressed and thus elongated.

All the red particles which are carried into the capillary system by the arteries, are returned from it by the small veins; none apparently are retained in the capillaries, at least in an animal which is not enfeebled. Doellinger and Dutrochet maintain that they have seen the red particles arrested in their course in the vascular canals, and become united with the tissue. I have myself, it is true, frequently observed this arrest of the red particles, particularly in enfeebled animals, and, formerly, thought it possible that the red particles of the blood might in this manner lose their mobility; but more accurate observations have convinced me that these stagnant globules are soon again set free, and that it is only in a state of extreme debility that a complete stagnation—or rather coagulation—of the blood occurs in the minute vessels. The occurrence of coagulation under such circumstances cannot, however, be supposed to explain the process of nutrition, being rather its very opposite. Not a single observer has confirmed the assertion of Doellinger relative to the union of the globules with the tissue, by which he supposed nutrition to be effected, and the observations, which I shall adduce in another place, render it very probable that nutrititon depends on a totally different process. Prevost and Dumas, it is true, inferred from their experiments, that the red particles exist in greater abundance in arterial than in venous blood; but this was a theoretical error. They supposed that all the fibrin of the blood was contained in the red particles; since, however, the fibrin is contained in solution in the fluid part of the blood, it is incorrect to estimate the quantity of red particles in the two kinds of blood from the amount of coagulum yielded.

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* Müller's Archiv. 1834, p. 365.

Self-propelling power of the blood.—Treviranus, Carus, Doellinger, and Oesterreicher have adopted the opinion of Kielmeyer, that the blood is endued with a power of self-propulsion, which they suppose to be exerted in the capillaries during life, independently of the heart's action, and to continue after the latter has ceased. This opinion seemed to be confirmed by the observations of Wolff and Pander, who asserted that, in the chick, blood is formed in the *area vasculosa*, and moves from its periphery towards the heart, before that organ has pulsated. This motion of the blood independent of and prior to the heart's action is, however, doubted by Baer: it appeared to him that the pulsation of the heart was first seen, and soon afterwards the motion of the blood in the transparent area, and that the influx of the blood from the *area vasculosa* to the heart took place last of all.* Nor has Wedemeyer been able to convince himself that the motion of the blood in the *area vasculosa* commences before the pulsation of the heart. The other arguments for the independent motion of the blood in the capillaries are derived from the continuance of the blood's motion in parts removed from the body. The idea of spontaneous motion in a fluid independent of attraction or repulsion from the sides of another object is itself inconceivable; but, even waiving this consideration, the facts brought forward in favour of the hypothesis, although in part correct, do not appear to me to justify the conclusions deduced from them. There are two conditions under which the blood in the capillaries of a transparent part separated from the body, may still be seen in motion by means of the microscope:—1. As long as the blood continues to flow from the divided vessels. Thus, for ten minutes after separating the foot of a frog from the body, I could still perceive motion of the blood from the minute vessels towards the larger; that is to say, towards the openings of the divided trunks. These movements, in my opinion, depend simply on the escape of the blood from the divided vessels, which by their elasticity contract to a less diameter than they previously had while in the state of forcible distension. The narrowing of the vessels can, in fact, be perceived by the aid of the microscope. If the divided surface from which the blood flows is elevated, together with the leg of the frog, the escape of the blood ceases sooner, and after five or six minutes not the slightest motion is perceptible in the capillary vessels. Wedemeyer's* observations agree in most particulars with mine, only that he does not mention the space of time during which the motions continue. 2. The second condition under which these motions are perceptible is, that the direct rays of the sun be allowed to fall on a moist part separated from the body. The surface of the part then becomes dry and wrinkled so quickly that the change is perceptible to the eye. This causes a more rapid emptying of the capillary vessels, which, together with the effect of illumination by the direct rays of the sun, produces a flickering appearance. Thus, in the wing of a bat removed from the body, a trace of this flickering motion of the blood will be perceived in spots even for many hours, but only at that part through which the most intense rays of the sun are at the time shining. The extraordinarily rapid shrivelling of the surface may be seen with the naked eye. If the part which is becoming dry is moistened again, the shrivelling, and with it also the flickering motion in the interior of the vessels, cease for some moments, but are renewed as soon as the evaporation and drying recommence. Even after a day and a half had elapsed, I could still see a flickering in the interior of the moistened wing when it was illumined by the direct light of the sun. Baumgärtner† observed the blood in the frog's foot continue in motion from three to five minutes after ligature of the artery, and attributed the motion to a reciprocal action exerted between the nerves and blood; it most probably arose from the contraction of vessels which had previously been distended; anastomoses also might give rise to such appearances. The ingenious experiments of Baumgärtner unfortunately do not clearly prove what they are intended to do. Moreover, according to my observation, the circulation in the capillaries generally ceases very quickly on the compression of the artery of the limb, when the spontaneous motion of the red particles ought certainly to be seen if it exists at all. Having destroyed the vitality of the heart of a frog by the application of *liquor kali caustici*, I could, by means of the microscope, for some time perceive motion of the blood in the capillary vessels, but it depended probably on the compression of the blood by the elastic coat of the arteries which had previously been in a state of forcible distension. In one case the blood in the capillaries remained fluid above an hour, and from time to time advanced a little, then receded, was still, and then again moved. These motions were probably produced by the compression of the vessels by slight motions of the frog, or of a single set of muscles of the leg. I deny, therefore, the existence of a self-propelling power in the blood.

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* Burdach's Physiol. ii. 261.

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* Ueber den Kreislauf des Blutes. Hanover, 1828, p. 233.

† Beobachtungen über die Nerven u. d. Blut. Freiburg, 1830.

If the blood moves independently of the heart's action, it must be by virtue of an attraction exerted on it by the solid walls of the capillary vessels, which seems to be what Baumgärtner and Koch suppose. If this attraction of the blood by the capillaries and the organised tissue really took place, it might produce a local accumulation of blood; but we cannot conceive how such attraction could aid the circulation of the blood, for it would cause the blood to become stationary in the capillaries, unless it is again admitted that this attraction of the capillaries for the blood is exerted only while the blood retains its arterial character, and ceases when it has become venous. It is only by such an action that the capillaries could assist the circulation. The congestion of certain parts at particular times is, however, no argument for the existence of this auxiliary force, for in this congestion there is accumulation as well as attraction of the blood. Although the circulation of the sap in plants, effected by means of attraction only, shows us the possibility of the occurrence of a similar phenomenon in animals, still there are at present no direct observations which prove it in a conclusive manner. The circular currents in many of the lower animals, which had been compared to the motion of the sap in the chara, and the movement of fluids in vessels, themselves destitute of motion, observed in Diplozon by Nordmann, and in some Distomata by Ehrenberg, have been recently shown to depend on the vibrations of cilia.*

Circulation of the lymph-globules in the blood.†—If the capillary circulation is attentively observed in the tail of the larva of the salamander or frog, or in the mesentery or web of the foot of the latter animal, it is perceived that besides the oval and flattened particles, the motion of which has been described in preceding paragraphs, there are other smaller and colourless bodies, of a spherical form and granular surface, moving more slowly and irregularly in the capillary vessels. These latter bodies are evidently identical with the so-called lymph-globules discovered by Professor Müller in the blood of the frog. Whenever one of these lymph-globules circulating with the current of blood comes into contact with the side of the vessel its motion is arrested, and it either becomes quite stationary for a time or is rolled along slowly and irregularly at the side of the current. The greater number of the lymph-globules, indeed, seem to move thus at the sides of the stream of blood, while the red particles pass rapidly along the centre of the vessel; and when the motion of the blood is not strong, several lymph-globules frequently collect in a capillary vessel, and for a time entirely prevent the passage of the red particles, but all eventually re-enter the current of blood; —none are observed to remain fixed and to unite with the tissue. These phenomena were first noticed by M. Poiseuille.* He inferred from them that the stratum of *liquor sanguinis* in contact with the parietes of the vessels is stationary, and that globules of blood which happen to be thrown into it lose, on that account, their rapid motion. But he had not recognised the different form and want of colour of the bodies which move thus slowly, or he would have perceived the insufficiency of this explanation. The red particles frequently pass in close contact with the walls of the vessels, and yet they for the most part glide smoothly onwards; hence it appears probable that, as M. E. H. Weber† supposes, the lymph-globules and walls of the vessels have a tendency to adhere to each other, and not to other bodies. Occasionally, however, one of the red particles of the blood is seen stationary at the side of the vessel, and if it remains thus for any length of time, it acquires, according to M. Weber, a globular form, loses its red colour, and rolls along the side of the vessel like the lymph-globules. He has observed that, in tadpoles kept some time out of water, the blood frequently became stagnant in a great part of the capillaries of the tail, and that when it began to circulate again the red particles adhered to each other, rolled along the sides of the vessels and lost their red colour. He states that he has seen this take place to a less extent in different parts of the tail of the larva, and of the mesentery of the full-grown frog, when they were not exhausted, and he conjectures that it has a relation to the process of nutrition. This transformation of the flattened and oval red particles into the globular and colourless lymph-globules, which, if confirmed, would be a highly important fact, has never been observed by the translator. He has arrested the circulation in the foot of the frog during more than two hours by ligature, but when the blood resumed its motion the proportion of colourless globules in it did not appear to be greater than before. In frogs which have been kept for a considerable period without food, the number of lymph-globules in comparison with the red particles in their blood, seems to increase; but this may have a different cause.

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* See the account of the circulation in the lower animals, p. 176.

† This entire paragraph on the circulation of the lymph-globules, is by the translator, Dr. Baly.

Vital turgescence of the blood-vessels.—Although it be denied that the circulation is in any way aided by an attraction between the blood and the capillaries, yet the existence of such an attraction or affinity may be admitted in the instance of the "turgescence, *turgor vitalis*, or orgasm," observed to take place in certain parts of the body, which are the seat of increased vital action, independently of the action of the heart.* This condition of turgescence is very evident in plants: thus, to the fruit-bud, which contains the impregnated ovum, there is, as Burdach remarks, an afflux of sap;—*ubi stimulus, ibi affluxus.*

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* Ann. des. Sc. Nat. Fevr. 1836. t. v. p. 111.

† Müller's Archiv. 1838, p. 457. In an earlier communication (*ibid.* 1837, p. 267,) M. Weber referred the phenomena above described to the circulation of lymph in a network of lymphatics external to the capillary blood-vessels. This error of M. Weber was noticed in the former edition of this work, having been pointed out to the translator by Dr. Sharpey, who had been long acquainted with the true nature of the phenomena in question. M. Ascherson afterwards (Müller's Archiv. 1837, p. 542,) showed the incorrectness of M. Weber's opinion.

The mutual vital action or affinity between the blood and the tissues of the body, which is an essential part of the process of nutrition, is, under many circumstances, greatly increased, and gives rise to an accumulation of blood in the dilated vessels of the organ. It is seen, for example, in the genitals during the state of sexual desire, in the uterus during pregnancy, in the stomach during digestion, and in the processes of the cranial bones, on which the stag's antlers afterwards rest, at the time of the reproduction of these parts. The local accumulation of blood, with the dilatation of old and the formation of new vessels, is, however, seen most frequently in the embryo, in which new organs are developed in succession by a process of this kind; while, on the other hand, other organs, such as the branchiæ of the salamander and frog, and the tail of the latter animal, become atrophied and perish as soon as the vital affinity which existed between the blood and their tissues ceases to be exerted.

The phenomena of turgescence have been supposed to depend on an increased action or contraction in the arteries. But arteries present no periodic contractions of a muscular nature; and a persistent contraction of the arteries, unless it were progressive, or vermicular, or aided by valves arranged in a determinate direction, would be quite inadequate to produce a state of turgescence in any part.

This condition of vascular turgescence may be excited very suddenly, as is seen in the instantaneous injection of the cheeks with blood in the act of blushing, and of the whole head under the influence of violent passions; in both of which instances the local phenomena are evidently induced by nervous influence. The active congestion of certain organs,—of the brain, for example,—while they are in a state of excitement, is a similar phenomenon.† Schwann‡ has proposed another explanation of these phenomena, by which the hypothesis of an attraction between the blood and the tissues is avoided. He supposes the constant vital contractility of particular arteries to be remitted so as to admit of their being more dilated by the pressure of the blood, and, consequently, to allow a greater accumulation of this fluid in the organs in which they are distributed.

If the organ which is susceptible of the increased affinity between the blood and the tissue is, at the same time, capable of considerable distension, tumefaction and *erection* take place.

Action of different substances on the capillaries.—Direct experiments to determine the action of different substances on the capillary vessels, by watching the changes produced by the application of these substances to the vessels of transparent parts, promised at first to increase considerably our knowledge of the action of the capillaries. But on this subject there still prevails the greatest confusion. The most interesting observations are those of Thomson, Wilson Philip, Hastings, Kaltenbrunner, Wedemeyer, and Koch. Two orders of changes are observed on the application of chemical agents to the small arteries, capillaries, and veins. In many instances,—for example, whenever common salt was applied,—dilatation of the capillaries ensued after a few minutes. In Wedemeyer's experiments, however, on the application of salt to the small arteries of the mesentery of the frog, contraction to the extent of $\frac{1}{8}$th of their diameter was the first effect, and this was followed by great dilatation. The application of ammonia was observed by Thomson to be followed by contraction of the vessels, with diminished rapidity of the circulation; while Wedemeyer and Hastings found it produce dilatation of the vessels with stagnation of the blood. Oesterreicher also observed dilatation follow the application of a weak solution of ammonia, while he found that substance of concentrated strength produce contraction of the vessels, and at last arrest of the circulation. Alcohol, according to Hastings, produced contraction of the capillaries: hot water had the same effect on frogs; the application of ice was also followed by contraction. Hastings remarked that these substances frequently caused contraction first, and afterwards dilatation. From the application of tincture of opium, tartaric acid, very dilute muriatic acid and alcohol, Wedemeyer obtained no constant result. In two instances only did alcohol cause retardation of the circulation, without, however, having excited distinct contraction in the small arteries. When dilatation of the vessels is produced, the circulation is generally at the same time retarded. Thomson is the only physiologist who has observed acceleration of the circulation accompanying dilatation of the vessels; and this was after the application of common salt. In cases in which the substance applied has produced contraction of the vessels, the effect on the circulation also varies, it being sometimes retarded, sometimes accelerated.

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* See Hebensbreit, De Turgore vitali. Lips. 1795. The view which this author takes of the subject is, however, very erroneous.

† See the remarks of Bonorden, in Meckel's Archiv. 1827, p. 537; and of Wedemeyer, l. c. 412.

‡ Encycl. Wörteb der med. Wissench. xiv. p. 233.

The blood must, *cæteris paribus*, flow more rapidly in a contracted vessel; but if its fluidity have been diminished, or coagulation induced, by the substance applied, its motion will be retarded. In a dilated vessel, the circulation must, *cæteris paribus*, be slower: increased rapidity of the circulation in such a state of the vessels can be accounted for only on the supposition that dilatation from an external cause may diminish the friction in the vessel.

The explanation of the phenomena detailed above is at present quite impossible. The contraction in all these cases may be a vital action of the animal tissue, or it may be merely a chemical effect, which would be produced equally well on dead matter,—the substance applied may be supposed, for example, to extract from the tissue a part of its water. The dilatation of the vessels produced by certain substances, may be a state of turgescence arising from an increased organic affinity, excited between the blood and the tissue:

it is, however, just as possible that it is merely the result of endosmosis. A salt when applied to a part, permeates the tissue till it reaches the capillary vessels; an attraction is then exerted between the salt and the blood, which has a tendency to dissolve the salt, as the salt has a tendency to dissolve itself in the blood; the blood will in consequence of this affinity be arrested and accumulated in the capillaries; the capillaries will be dilated, and the circulation in them retarded. It is very probable that dilatation of the capillaries, when produced by the application of a salt, is dependent on endosmosis alone.

State of the capillaries in inflammation.—The results of the experiments detailed above appear, then, to admit of such different explanations, that they can be of scarcely any assistance in determining the state of the capillaries in inflammation. I shall, therefore, simply detail the phenomena of this morbid process, as they have been observed and described by Thomson,* Kaltenbrunner,† and Koch.‡

The minute vessels of an inflamed organ contain at every stage of the process an increased quantity of blood: at the commencement of the inflammation, the blood flows into the capillaries in larger quantity than natural, circulates through them rapidly, and escapes from them into the veins without great difficulty; but in a more advanced stage of the disease, the circulation becomes impeded, and stagnates in the distended capillaries; at first single vessels only, but at last all the capillaries of the part, are seen filled with blood, which is motionless, and if not coagulated, has at any rate undergone some change. Koch says that the colouring matter of the globules is dissolved by the serum in the inflamed part: this, however, is not probable, for in that case the fibrinous exudation would be coloured red. According to Koch, no new vessels are formed in inflamed parts; it must, however, be remembered that they are certainly developed in the fibrin effused during the inflammatory process. When the inflammatory congestion has attained its highest degree in membranes which have a free surface, they pour out the dissolved fibrin of the blood. The fibrinous fluid or lymph coagulates on the surface of the membrane, forming pseudo-membranes. If the inflammation is situated in a part where there is no free surface on which this exudation can take place, the coagulable matter accumulates in the capillary vessels themselves. When the consequent arrest of the circulation takes place only in isolated tracks of the capillary system, while the circulation of the organ is carried on, though incompletely, by the other capillaries; the part is merely rendered denser in texture,—a state which is called hepatisation, when it occurs in the lungs; in other organs, induration. If the violence of the inflammation is so great that the circulation in the organ is completely arrested, the blood in all the capillaries is not merely coagulated, but decomposed; while the tissue itself undergoes decomposition: such a part is said to be gangrenous, or mortified,—its vitality is lost. Thomson has observed, that the vessels in gangrenous parts are sometimes filled with coagulated fibrin, and sometimes obliterated by the inflammatory process. Mortification ensues more readily when the nervous energy is diminished, and in paralysed parts.

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* Lectures on Inflammation, translated into German by Krukenberg. Halle, 1820.

† Exp. circa statum sanguinis et vasorum in inflammatione. Monach. 1826.

‡ Koch has given a review of the subject, with original experiments, in Meckel's Archiv. Bd. vi.

If, after the congestion and effusion of lymph have taken place, the inflammation is still kept up, either by the persistence of the same causes, or by the accession of new, the tissue of the organ undergoes a peculiar change. The decomposed molecules of the tissue are separated in the form of pus,—a matter consisting of globules larger than those of the blood. No one, not even Kaltenbrunner, has observed satisfactorily by the aid of the microscope the formation of pus. Cold-blooded animals are not adapted for such an observation; it ought to be instituted on Mammalia,—on the wings of the bat, for example.*

Nature of the inflammatory process.—In inflammation the phenomena are so far similar to those of vital turgescence, or orgasm, that the blood is attracted in increased quantity to the part, and escapes from it with difficulty. But the effects of inflammation show that it would be a great error to regard it as identical with increased vital action. In inflammation the function of the part is disturbed in consequence of the change of composition produced in it by the exciting cause of the inflammation; while nature makes an effort to repair this material change. In the reproduction of the antlers of the stag, in the phenomenon of erection, and in the turgid state of the uterus after conception, the turgescence is readily combined with increased vital power, and the excitement and the vital energy in these cases advance to a certain extent *pari passu;* but in inflammation the material change is the only part of the process which goes on increasing. The appearance of turgescence which arises from the blood being attracted and retained by the inflamed tissues,—perhaps for the purpose of restoring them to their natural condition,—is gradually exchanged for that of gangrene. The latter state ensues as soon as the change produced in the tissues is so great that they lose the power, which in the healthy state they possess, of preserving the vital properties of the blood, and this fluid becomes decomposed in the vessels. Inflammation is produced by irritation of the capillaries, but itself consists neither in an increased nor in a diminished vitality. It is a peculiar state which may occur with the general vital powers in their normal state, or with these powers depressed; and which, in proportion to the degree of its development, if in an important organ, always exhausts the vital powers, even though they were not previously enfeebled. It is in fact a reciprocal action, morbid in its nature, which is set up between the tissues and the blood, in consequence of the changes produced in the part by the irritating cause, and which is compounded of the original lesion of the part, of a local tendency to decomposition, and of a vital action striving to counterbalance that tendency. The vital action of the part sometimes overcomes the morbid tendency, as is exemplified by a wound when healing; sometimes it does not.

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* The nature of pus and its mode of formation have been described more fully in Book I. Chap. II. b. on Regeneration with Suppuration.

When inflammation is excited in the skin by a blistering plaster, it pours out at first, in place of its ordinary secretions, a fluid which contains merely albumen in solution. A higher degree of inflammation may give rise, in any membrane, to the exudation of fibrin; and in a further stage of the inflammatory process pus only is formed.

Influence of the nerves on the circulation in the capillaries.— Several physiologists have recently sought to prove, that the nerves have a great share in keeping up the circulation in the capillary vessels. Treviranus and Baumgärtner have done most to support this theory. But although it is certain that turgescence of the tissues—their attraction of the nutritive fluid—is dependent on the influence of the nerves, it does not necessarily follow that this influence should at all aid the circulation. The numerous experiments of Baumgärtner are far from being convincing. He himself confesses that many of them are not strictly conclusive; and, if proofs are imperfect, their number does not better establish the fact. Baumgärtner directed a strong galvanic current through the ischiadic nerve to the foot of a frog; the irritability of the nerve was destroyed, and in most cases the circulation in the limb was arrested. But here, by destroying the nervous energy of the part, the influence by which the coagulation of the fibrin is prevented was abolished; and, besides this, it must be remembered that galvanism will produce coagulation of the albumen in the blood. After destruction of the spinal cord and brain, Baumgärtner saw the motion of the blood in capillaries become slower, although the heart continued to beat. But here, again, the motion of the heart itself was weakened; and experiments which rest upon an indefinite "more" or "less," are not proofs.

Treviranus asserted that division of the ischiadic nerve in the frog caused the circulation in the web of the foot to cease. But even Baumgärtner denies that this is the case if the web is kept properly moist.

The numerous experiments of Dr. Wilson Philip* also fail completely to establish the influence of the nerves on the circulation in the capillaries. The retardation or cessation of the circulation in the capillaries which he observed when opium or infusion of tobacco was applied to the brain and spinal cord, or when these parts were suddenly destroyed, was dependent on the effect which was produced simultaneously on the heart. Koch† also made an ingenious and simple experiment with a view to determine the same point. He amputated the leg of a small frog, and found that the motion of the blood in the capillaries of the web of the foot continued only for three minutes. He then, in another frog, divided all the parts of the thigh but the ischiadic nerve, by which he left the limb attached to the body; and he now perceived motions in the capillaries for the space of a quarter or half an hour. I have repeated this experiment, but not with the same result. The motion of the blood in the capillaries continued about ten minutes when the limb was completely separated from the body in strong frogs; and there was no difference in respect to time when it was left attached by the ischiadic nerve. In this experiment an error may be induced by the frog retaining the power of producing voluntary contractions of the muscles of the limb, as long as the ischiadic nerve maintains its connection with the nervous centres. After each contraction of the limb, a slight motion of the blood in the capillaries is perceived; but the cause of this is evidently mechanical.

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* Experimental Inquiry into the Laws of the Vital Functions.

† Meckel's Archiv. 1827, p. 443.

In the following experiment I avoided this cause of error:—I laid open the spinal canal in a frog; and while my assistant, M. Hoevel, applied the wires of a simple galvanic circle to the posterior roots of the spinal nerves,—the irritation of which excites no contractions of the muscles,—I watched the circulation in the foot of the frog. At the moment when the galvanic stimulus was applied, no change was produced in the motion of the blood. This experiment, however, is not conclusive; for it might be the anterior roots of the nerves from which an influence on the circulation is derived.

From the facts which we have detailed, it appears most probable that the nerves do not really assist in carrying on the circulation in the capillaries, although it is certain that nervous influence is the principal cause of the accumulation of the blood in the capillaries of certain parts during the state of vital turgescence. The observation that in a frog much exhausted the impulses communicated to the blood by the feeble contractions of the heart are perceptible in the capillaries, proves that no other force than that of the heart is required to support the circulation.

OF THE VEINS.

Auxiliaries of the venous circulation.—The propulsive force of the heart transmitted through the arteries and capillaries is aided in accomplishing the circulation through the venous system by the action of the *valves*, with which the veins are provided, and which are so arranged that any intermitting pressure on these vessels favours the motion of the blood towards the heart. Hence the want of proper bodily exercise must have an injurious effect on the circulation, if it were merely from the loss of the aid which the action of the muscles affords to the motion of the blood in the veins. The veins themselves, with the exception of the root of the vena cava and of the pulmonary veins, have no contractile power.

Dr. Marshall Hall has discovered in the eel a kind of auxiliary venous heart, situated at each side of the last caudal vertebra, which pumps the blood out of the small veins of the extremity of the caudal fin into the vena caudalis. But I have not found a similar organ in other fishes.

Active dilatation of the heart.—Many recent writers, believing that the contractile power of the heart is insufficient for the completion of the circulation of the blood, ascribe some share in this function to a power of suction which they suppose to be possessed by the heart. They imagine that, after the heart has contracted, its cavities return to a state intermediate between dilatation and contraction, so as to give rise to a relative vacuum.* The degree to which the heart thus dilates after its contraction, independent of being dilated by a fluid, can be but slight. But let us inquire how much effect is to be attributed to such a dilatation of the heart. During the contraction of the auricle, the great veins become more distended with blood, either on account of the reflux of a part of the blood of the auricle into them, or from that which they were pouring into the auricle being arrested in its progress. During the dilatation of the auricles the distension of the veins diminishes. This was observed by Magendie and Wedemeyer, and I have myself witnessed it in the dog. A knowledge of this fact is necessary in forming an opinion on the following experiments:—Wedemeyer and Guenther, having tied the jugular vein in a horse, made an opening into it between the ligature and the heart, and introduced a catheter, to which a bent glass tube had been cemented. The longer descending branch of the tube (two feet in length) was placed in a glass filled with water. At first the inspirations and the contractions of the heart were nearly simultaneous and of the same frequency,—namely, thirty in a minute,—and the coloured water rose suddenly two or more inches in the tube at the moment of each inspiration and pulsation of the heart, and sank again each time to its former level. The inspirations gradually become twice as frequent as the pulsations of the heart; and Wedemeyer and Guenther now observed for a long period, that the rise of the fluid did not take place at each respiration, but at every beat of the heart, and consequently simultaneously with each dilatation of the auricle. This experiment seems to prove beyond doubt that the heart exerts a power of suction. This power is not, however, the principal cause of the blood's motion in the veins. The fact, that large veins when divided continue to pour out blood from that portion of the vein which is distant from the heart, and connected with the capillaries and arteries, proves that the propelling power of the heart's contraction extends to the veins; but Magendie has shown that the stream of venous blood from the lower end of a divided vein becomes stronger during each expiration, consequently that the effect of the compression of the arterial trunks which takes place during expiration also extends to the veins; and it is evident that the force thus exerted is far inferior to that of the heart's contractions.

The circulation in fishes likewise shows that the passage of the blood through a system of capillaries does not destroy the *vis à tergo* by which it is propelled; for in these animals the heart sends the blood through two systems of capillaries; first through that of the branchiæ, whence it passes into the systemic arteries, which, as Nysten has shown, have themselves no contractile power; and afterwards through the general capillary system of the body. In all vertebrate animals, indeed, the *vis à tergo* derived from the heart is sufficient to propel the blood through the capillaries of the liver, after it has already circulated through those of the other abdominal viscera.

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* See Zugenbuehler, Diss. de motu sang. per venas; Arch. der Med. und Chir. Schweiz. Aerzte. 1816; Schubarth, in Gilbert's Annalen, 1817: and, on the other hand, Carus, in Meckel's Archiv. iv. 412.

Influence of respiration.—Sir David Barry has recently given a new turn to these inquiries respecting the circulation in the veins. The heart, he says, when distended with blood, completely fills the pericardium; but, when it contracts, it no longer occupies the same space, and a partial vacuum ensues. To enable the auricles to fill this vacuum, the blood rushes into them from the great venous trunks. But Sir D. Barry attributes more importance to the effect of inspiration. During inspiration, he says, a partial vacuum is formed in the thoracic cavity, and all surrounding fluid must strive to enter to fill this vacuum; the atmospheric air rushes in through the trachea, distending the lungs in proportion to the dilatation of the thorax, and in the same way the fluids in the vessels of the body being subject to the pressure of the atmospheric air, will be forced into the cavity of the thorax and distend the trunks of the great vessels contained in it. In consequence, however, of a vacuum being formed in the pericardium at each contraction of the heart, the blood of the great venous trunks is drawn into the auricles to fill this vacuum; so that the afflux of blood to the cavity of the thorax during inspiration takes place principally towards the auricles. To prove the correctness of his theory, he performed the following experiment:—He introduced one end of a bent glass tube into the jugular vein of an animal, the vein being tied above the point where the tube was inserted; the inferior end of the tube was immersed in some coloured fluid. He now observed that at the time of each inspiration the fluid ascended in the tube, while during expiration it either remained stationary, or even sank. When the tube was introduced into the pericardium itself, he observed the same ascent of the fluid.

Poiseuille has instituted some experiments to determine the same question, but in a more accurate manner. He employed the instrument described at page 215. A solution of carbonate of soda was poured into the tube, filling both the perpendicular branches till it rose to a level with the horizontal portion; this point was the 0 of the scale. When the horizontal portion of the instrument thus prepared is connected with the cavity of a vein, if any suction is exerted in the vein, a part of the fluid will be drawn out of the instrument, and its level in the great perpendicular branch will fall; if, on the other hand, any pressure is exerted by the blood in the vein on the fluid in the horizontal portion, the level of the fluid in the branch will rise. The instrument was connected with the jugular vein of a dog; and it was observed that during expiration the fluid rose in the branch, and fell during inspiration; the rise at first equalled 3 inches 4 lines, the fall was 3 inches 6 lines below the previous level; afterwards the fluid ascended only 2 inches 4 lines, and fell 2 inches 9 lines below the level. During great muscular efforts, the ascent of the fluid at the time of expiration was as much as 5 inches 6 lines, or 6 inches one line above the level; and the descent during inspiration 9 inches 5 lines, or 9 inches 11 lines below it. These experiments, which on repetition afforded the same results, confirmed Barry's opinion that during inspiration the venous blood of the body is drawn into the venous trunks contained within the thorax. While, on the other hand, the effect of expiration in repelling the blood must be prevented by the action of the valves, and by the pressure exerted on the blood in the veins by the muscles.

Sir D. Barry, however, estimated too highly the influence of inspiration on the motion of the blood. It is observable only in the large veins near the thorax. Poiseuille could not detect it by means of his instrument in veins more distant from the heart,—for example, in the veins of the extremities. The act of inspiration empties the large veins in the thorax, and less resistance is in consequence offered to the entrance of the blood from the other veins; but it cannot be the principal cause of the motion of the blood in the veins; and in the reptiles which breathe by the movements of deglutition, in fishes, and in the fœtus, no movement of inspiration is performed. There can be no doubt, therefore, that the same power which moves the blood in the arteries, also effects its motion in the capillaries and its return to the heart through the veins; and that by the influence of inspiration on the great venous trunks, by the sucking action of the heart, and by the action of the valves, a part only of the resistance which opposes the course of the venous blood is overcome.

The changes produced in the motion of the blood by the contraction of the thorax during expiration, give rise to the tumefaction of certain parts. The vascular trunks are in expiration so compressed, that the blood is sent with increased force into the arteries, while the influx of blood into the right auricle is arrested. The consequence of this is not merely that the jugular veins become distended, but that even the brain is more fully injected with blood. Hence in cases where a portion of the skull has been removed by the trephine, the brain is in most cases seen to be elevated somewhat during expiration, and to collapse again during inspiration. Magendie declares that he has also observed this to take place in the spinal cord. In the natural state, the cranial cavity being inclosed by solid walls, no such movements of the brain can be caused by respiration; the brain cannot then alter its volume. All that has been advanced in favour of such a change of volume taking place in the natural state, is refuted by the physical impossibility of its occurrence.

The effects of impediment to the circulation in the larger veins are effusion of the watery and albuminous parts of the blood into the serous cavities and the cellular tissue. The fibrin is usually not effused; but in a case of ascites observed by Dr. A. Magnus, the fluid drawn off by paracentesis coagulated completely within a few minutes after its removal from the body.

Arterial and venous plexuses, or retia mirabilia.

These vascular plexuses are, without doubt, to be reckoned among the facts in comparative anatomy which are of great physiological interest. They are structures formed by the sudden division of an artery or vein into the tuft of smaller twigs, or into numerous anastomosing branches, which may or may not unite again into a single trunk. The cases in which this reunion takes place are the more rare. It is met with in the arteries of the extremities and tail of some tardigrade Mammalia, such as Bradypus, Myrmecophaga, Manis, and Stenops.* The same structure occurs, however, in parts where it can have no relation to muscular motion; thus the *rete mirabile caroticum* in the Ruminantia and hog is formed by branches of the common carotid which again unite to form the cerebral carotid. Rapp† shows, that in animals provided with a *rete mirabile caroticum*, the vertebral artery does not go to the brain, but is connected with the external carotid, as in the goat and calf, or where it has connections with the rete mirabile of the carotid, is still principally distributed to the muscles of the neck, as in the sheep. Similar plexuses of arteries exist in the orbits of Ruminantia, feline animals, and birds, according to Rapp and Barkow,‡ and give origin to the arteries of the eyeball. The vascular plexuses connected with the intercostal arteries and iliac veins of the Delphinæ are of immense size.§ In some birds the arteria tibialis forms a *rete mirabile*. Among reptiles and Amphibia we know only the small vascular plexus seated on the trunk of the carotid of the frog, the so-named carotid gland. Some of the largest structures of this kind are those recently discovered by Eschricht and myself in certain fishes; and they are the more remarkable for being composed both of arteries and veins.

These vascular structures have either a mechanical or a chemical influence on the blood. The transmission of the blood through numerous small tubes which unite again to form single trunks, appears to have the object of producing a local retardation of the circulation by the increased friction to which it gives rise. This view is applicable to all forms of rete mirabile. The theory that they are destined to secure the continuance of the circulation in the extremities and tail of some climbing animals during prolonged action of the muscles, will apply to a few forms only. There are at present no other grounds for supposing that these vascular plexuses have a chemical action than their analogy with the plexuses of lymphatics and the lymphatic glands, and the observation of Dr. J. Davy, that the thunny has the power of maintaining a temperature much above that of the surrounding medium. This supposition has, however, little probability in its favour. The passage of the blood of the digestive organs through two capillary systems appears in all Vertebrata to be partly intended to produce a local retardation of the circulation; in the fishes in which the vessels of the abdominal viscera form these vascular plexuses, the motion of the blood must be still more retarded.

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* Sir A. Carlisle, Philos. Transact. 1800. Vrolik, De peculiari Art. Extremitatum in nonnullis Animalibus Dispositione. Amsterd. 1826.

† Meckel's Archiv. 1827.

‡ Meckel's Archiv. 1829.

§ Breschet, Hist. Anat. et Physiol. d'un Organe de Nature vasculaire découverte dans les Cetaces. Paris, 1836.—Baer, Nov. Act. xvii. These vascular plexuses were known to Tyson (Anatomy of a Porpoise), and were more accurately described by Mr. Hunter (On the Structure and Economy of Whales).

The erectile structures.

The only erectile parts are the penis, and in some cases, perhaps, the clitoris. The apparently erectile appendage on the head of the turkey has been shown by Schwann to consist in great part of muscular fibres, and to contain no trace of erectile tissue. As it regards the erection of the nipple in the male subject, as well as in women, while suckling, these seem to depend on the action of contractile tissue similar to that which exists in the dartos and prepuce, and apparently also around the follicles of the skin.

Erection seems to belong to the class of phenomena to which the term, "turgescence, or *turgor vitalis*," is applied; but it is distinguished by its occurring only in parts which have a peculiar structure.

In erectile parts the vessels are susceptible of great dilatation, and the veins very sinuous, forming numerous anastomoses and plexuses; so that the capacity of all the plexuses, when dilated, exceeds beyond comparison that of the arteries and veins which convey the blood to and from them. In the undistended state, the same quantity of blood is sent to the extensile vessels as returns from them; but, during the state of erection, the blood is probably retained in them, in consequence of the affinity between it and the parietes of the vessels being increased.

When the erectile part is supported by a strong fibrous tissue, lying in the intervals of the venous plexuses and connected with an external fibrous tunic, as is the case in the corpora cavernosa penis, it acquires, during the state of erection, great tension and firmness.

Injected matters pass pretty freely from the arteries of the penis into the veins, particularly in the *corpus spongiosum urethræ*, and glans. Professor M. J. Weber has shown to me a series of beautiful preparations of the penis injected from the arteries.* In the corpus cavernosum of the penis of the horse there are, between the anastomosing veins, a number of pale red bundles of fibres, which, for the most part, run longitudinally, but are connected by transverse bands. Viewed by the microscope, these fibres do not present any resemblance to muscular fibres. Boiled in water for seven hours they yield no gelatin, and their solution in acetic acid is precipitated by ferrocyanuret of potassium. All we can conclude from this analysis is, that they do not belong to the cellular, tendinous, or elastic tissues.

I could excite no contraction in the fibres of the corpus cavernosum, by means of galvanism, in a living horse. Hence they would seem not to be muscular.*

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* Cuvier, Anat. Comparée, t. iv.; Moreschi, Meckel's Archiv. v. 403; Ribes, ibid. 447; Tiedemann, Meckel's Archiv. ii. 95; Panizza, Osservazioni Antropozootomicofisiologiche. Pavia, 1830.

The principal exciting cause of the erection of the penis is, as is well known, nervous irritation, originating in the part itself or derived from the brain and spinal marrow. Congestion of the brain and spinal cord has the same effect, and it is from this cause that the above-mentioned phenomena are sometimes produced in persons hanged. The nervous influence is communicated to the penis by the pudic nerves which ramify in its vascular tissue. Guenther has observed that, after division of these nerves in the horse, the penis is no longer capable of erection.† The stallion on which the experiment was performed was led to a mare; he showed desire to cover, but no erection of the penis took place. On the following day the penis was swollen, but not in a state of erection. More recently Guenther‡ has repeated this experiment, and with a similar result as to the effect on the penis; but the horse did not, as in the former instance, show any sexual desire when led to a mare after the operation.

My discovery of the remarkable structure of the arteries of the *corpora cavernosa penis* throws new light on the phenomena of erection. The arteries of the *corpora cavernosa* have two sets of branches. When the *arteria corporis cavernosi* is injected with size and vermilion, the injected matter always fills the venous cells; and if it is afterwards washed from them, the *arteriæ helicinæ* will be seen injected.§ They come off from the side of the arteries, and consist of short tendril-like branches, terminating abruptly by a rounded, apparently closed, extremity, turned back somewhat on itself. The means by which during life they are enabled to force blood into the cells, must be an increased attraction excited between their coats and the blood by the nervous influence transmitted to them from the spinal cord, in consequence of which an increased quantity of blood flows to them. This discovery throws new light, at the same time, upon the mutual action of the blood and smaller vessels in other parts, and upon the phenomenon of active turgescence, or turgor vitalis.‖ The blood is returned from the corpora cavernosa partly by small veins, running at the sides and on the surface of these bodies into the vena dorsalis, partly by deeper veins which issue from the corpora cavernosa at their root, and enter immediately the venous plexus, situated behind the symphisis pubis. The fact, then, that the vena dorsalis does not return the blood from

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[*] Müller's Archiv. 1834, p. 50; 1835, p. 26.

[†] Meckel's Archiv. 1828, p. 364.

[‡] Untersuch und Erfahr. im Gebiete der Anat. Physiol. und Thier-arzneikunde. Abstracts are given in Müller's Archiv. 1838, p. clxiii. and in Valentin's Repertorium, 1838.

[§] Prof. Valentin (Müller's Archiv. 1838. p. 182) denies the existence of the arteriæ helicinæ: he supposes erection to be in a great measure due to the active dilatation of the veins by muscular fibres, attached to tendinous tissue between the anastomosing veins; but the characters on which he founds his belief that the fibres in question are muscular, are not conclusive.

[‖] Müller's Archiv. 1834, p. 202, tab. xiii.

the deep veins, shows that no pressure on the former vein alone can cause accumulation of blood in the penis.*

The sensations of the organs of generation are due to the pudic nerves; but the act of erection seems to be principally dependent on the organic nervous system, a plexus of delicate filaments belonging to which is given off by the hypogastric plexus, and passes under the arch of the pubis so as to reach the root of the penis; where the nervous filaments composing it unite with branches of the pudic nerve, enter with them the substance of the *corpora cavernosa penis* and *corpus spongiosum urethræ*, and ramify upon the blood-vessels. The sensitive nerves of the penis transmit impressions to the spinal cord, and through the medium of it probably excite the action of the organic nerves and vessels necessary for the production of erection; the effusion of blood into the corpora cavernosa follows, and the distention of the erectile tissue is rendered more perfect by the contraction of the *musculi ischiocavernosi*, or *erectores penis*, which impedes the escape of the blood by the veins.

In order to ascertain the amount of force necessary to give the proper rigidity to the corpora cavernosa by the propulsion of fluid into them, I fixed into an opening made into one of those bodies in a dead subject, a glass tube six feet in length, and filled this tube, held perpendicularly, with water, while the return of the water by the veins was prevented by pressure within the pelvis. When the column of water attained the height of six feet, the erection of the penis was perfect. Hence it appeared that the blood accumulated in the penis, during erection, is subjected to a pressure equal to that of a column of water of six feet in height, which is about the same pressure as that with which the blood moves in the arteries.

CHAPTER V.

OF THE ACTION OF THE BLOOD-VESSELS IN THE PROCESS OF ABSORPTION AND EXUDATION.

a. Of Absorption.

The office of absorption was ascribed to the veins until after the discovery of the lacteals by Asellius, in 1622, and subsequently of similar vessels—the lymphatics—in most other parts of the body, when these latter vessels were supposed to be the sole organs of absorption. The fact of the lacteals becoming turgid with chyle soon after taking food, and the arrangement of their valves, which is such as to favour the course of the chyle and lymph towards the thoracic duct, and to prevent its motion in the opposite direction, are corroborative of the opinion that they perform the function of absorption. It has, however, at different times been remarked that the lymphatics cannot be the sole organs for the fulfilment of this office. The absorption of the osseous matter in the interior of the bones in the formation of their cells, and the absorption of the alveoli of the teeth in old persons, are facts well known, and yet there are no lymphatics in bones. It is certain also that pus, portions of the lens, and blood in the interior of the eye, become absorbed, and nevertheless no lymphatics have been discovered in the interior of that organ. Lastly, we need only instance the absorption of the yolk of the egg by the germinal membrane, in which no one will assert that there are lymphatics during the first days of incubation; if the invertebrate animals which possess no lymphatics, did not sufficiently prove the possibility of absorption being performed without the agency of these vessels.

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* See the article "Erection," by Müller, in the Encyclop. Wörtenbuch d. medicin. Wissench.

Proofs of absorption by the blood-vessels.—It required, however, a long course of experiments to establish the fact of the immediate absorption of matters into the blood without the aid of lymphatics. Magendie, Emmert, Mayer, Lawrence, B. H. Coates, Harlan, Tiedemann, Gmelin, and Westrumb, have particularly distinguished themselves in this inquiry.

Delille and Magendie having divided all the parts of the thigh of a dog except the crural artery and vein, leaving merely these vessels, which were dissected quite clean, and freed from their cellular coat, to maintain the connection of the limb with the trunk, then inserted two grains of a strong poison (the upas ticuti) into a wound in the foot. The action of the poison was as rapid as if the limb had been previously uninjured. The symptoms began to show themselves in four minutes, and in ten minutes the animal was dead.

The same physiologists made a similar experiment on a convolution of intestine in a dog, in which the lacteals had been previously made visible by giving the animal a good meal. The intestine was tied at two points, with an interval of fifteen or sixteen inches; the lacteals of this portion of intestine were then tied each with two ligatures and divided. They satisfied themselves that no other lacteals ran from this part of the intestine, so that its only means of communication with the circulation were the arteries and veins. They now injected into the intestine two ounces of decoction of nux vomica, and retained it there by a ligature. Symptoms of poisoning ensued in six minutes.*

Magendie laid bare one of the jugular veins in a young dog of six weeks old, and isolated it from surrounding parts in its whole length, so that he could pass a card beneath it. He then applied freely to the vein a watery solution of spirituous extract of nux vomica. The symptoms of poisoning appeared before the fourth minute; when a similar experiment was made on an adult dog, the symptoms came on in ten minutes.†

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* Elements of Physiol. translated by Milligan, 4th ed. p. 314.

† Magendie, l. c. p. 358.

Segalas[*] has repeated these experiments in a different manner. He tied the blood-vessels, or merely the veins of a portion of intestine, the lymphatics being uninjured, and was then unable to kill a dog, even in an hour, by means of poison introduced into the intestine.

The results of Mayer's[†] experiments, in which he injected a solution of prussiate of potash into the lungs, must be more accurately detailed. As early as from two to five minutes after its injection into the lungs, the salt could be detected in the blood by the green or blue precipitate produced in the serum by the addition of muriate or sulphate of iron. The rapidity with which the prussiate of potash enters the blood, is too great for it to be explained by means of the slow circulation of the lymph. The salt was detected in the blood long before it was perceptible in the chyle, and in the left side of the heart before a trace of it could be detected in the right cavities; while, if the absorption had been effected by the lymphatics, the course of the lymph being first into the venous blood of the body, the salt absorbed ought to be detected first in the right cavities of the heart. Eight minutes after its injection into the lungs, prussiate of potash shows itself in the urine. It is found also in the skin, in the fluid of the articular cavities, in the abdominal cavity, in the pleura, in the pericardium, in the fat, in the fibrous membranes,—for instance, the dura mater,—in the aponeuroses, in the arachnoid, in the capsular and lateral ligaments, in the internal ligaments of joints,—as the crucial ligaments of the knee-joints and the *ligamentum teres* of the acetabulum,—in the perichondrium, and in the valves of the heart. The kidneys were the only glands in which it could be detected; prussiate of potash, like most salts, being excreted from the blood by the kidneys. The liver did not become stained on its external surface when the salt of iron was applied, but the colour was evident in the interior of the gland, although still only around the large vessels which were enclosed in the cellular tissue of the capsule of Glisson: no change of colour was produced in the bile, and a very slight one only in the milk. In the testicle, the salivary and pancreatic glands, and more especially in the cellular tissue of these parts, the colouring was more distinct. The spleen evidenced no change of colour, the suprarenal capsules scarcely any, and none was produced in the muscles, except at the parts where the bundles of muscular fibre were enveloped in fibrous membrane. The nerves became green externally, but this was dependent on the cellular membrane which surrounded them; the nervous substance itself, and the brain and spinal cord, displayed not the slightest alteration of colour. The colour of bone also remained unchanged. The reason of these differences is, perhaps, that the prussiate of potash is decomposed in some tissues, so as to render its detection by chemical tests impossible, for it must be distributed with the blood equally to all parts.

Some of the experiments which the committee of the Academy of

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[*] Magendie's Journal de Physiolog. ii. p. 117.

[†] Meckel's Archiv. t. iii. 1817, p. 485.

Medicine of Philadelphia, Drs. Lawrence, Coates and Harlan, instituted,* seem to be opposed to the results obtained by Mayer, and by all the observers hitherto mentioned; and are in favour of the opinion that absorption is performed chiefly by the lymphatics; but they are not conclusive: they merely prove that chemical agents are absorbed by the lymphatics as well as by the capillaries. Westrumb† detected prussiate of potash in the urine two minutes after injecting it into the stomach, while the lymph and chyle contained none. The ureters had been divided, and tubes fixed in them, from which the urine was received.

Tiedemann and Gmelin in numerous and well conducted experiments found that foreign (saline) matters introduced into the stomach by the mouth very rarely found entrance into the chyle; colouring matters never. These results, which, from the accuracy with which the experiments were performed, can be in great measure depended upon, agree with those of the experiments made by Hallé‡ and Magendie.§ On the other hand, they are opposed to those of Martin, Lister, and Musgrave,‖ of Hunter, Haller, and Blumenbach, as well as of Viridet and Mattei, who assert that they have observed a yellow or red colour in the chyle after food consisting of yolk of eggs or red beet had been taken.

Fodera¶ and Poiseuille** detected prussiate of potash both in the veins and lacteals soon after its injection into the intestine of a living animal. Schroeder van der Kolk could perceive it only in the lacteals, on repeating this experiment. It may be remarked, that a blue tint is exceedingly difficult to detect in the blood itself, and cannot be recognised with certainty except in the serum of the blood. Lawrence and Coates†† did not detect the salt in the blood before it was perceptible in the upper part of the thoracic duct.

Several experiments to determine the influence of ligature of the thoracic duct on absorption have been made by Brodie, Magendie, Delille, and Segalas. In Brodie's‡‡ experiments, the fatal effects of alcohol and woorara poison were still produced, after the thoracic duct was tied.

Since, however, the thoracic duct has sometimes in animals communications with veins,—for instance, branches joining the vena azygos, as in the hog,—and since even a right thoracic duct sometimes exists, while the absorbent vessels have frequent communications with each other, the application of a ligature to the thoracic duct cannot absolutely prevent the passage of the poisoned lymph into the blood.

Emmert has demonstrated the immediate passage of matters into the blood, by showing that they do not enter the circulation when the blood-vessels are tied. Jacobson,[*] lastly, has shown, that in mollusca, which possess no lymphatics, prussiate of potash, nevertheless, finds its way readily into the blood from every surface to which it is applied, and is again eliminated from the blood by the secreting organs,—the lungs, liver, and *saccus calcareus*.[†]

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* Philadelph. Journ. N. 6. Froriep's Not. N. 49.

† Meckel's Archiv. vii. 525, 540.

‡ Fourcroy's Système des Connaiss. Chim. 10, 66.

§ Loc. cit.

‖ Phil. Trans. 1701, 819.

¶ Recherch. exp. sur l'exhalation et l'absorption. Par. 1824.

** Breschet's Système Lymphatique, p. 211.

†† Froriep's Not. 77. Philadelphia Journal, Aug. 1822; and London Med. and Phys. Journal, 1823, v. 49, p. 15.

‡‡ Phil. Trans. 1811.

The immediate absorption of matters by the capillary blood-vessels is proved by all these experiments, but especially by the extraordinarily rapid effects of poison; for it is equally certain that the general effects of poisoning depend, not on nervous communication, but wholly on the noxious substance entering the circulation.

All the phenomena which we have detailed might, however, be dependent on absorption by the lymphatics, if, as some recent writers suppose, the lymphatics and small veins do really communicate. But this objection may be completely set aside by the known laws of the imbibition of animal tissues.

Imbibition.—Until recently the passage of matters into the blood was supposed to depend on a peculiar absorbing power of the veins. But it is now known that fluid matters may find their way into the blood of the capillaries, without the aid of this imaginary power of absorption; and from the capillaries they necessarily pass first into the veins, the direction in which all the blood of the capillaries moves being from the arteries towards the veins and the heart. The primary phenomenon in the immediate absorption of substances in solution into the blood, is the permeation of the animal tissues by fluids brought into contact with them. The property of permeability by fluids possessed by tissues even after death, depends upon their invisible porosity, and is termed "imbibition." This kind of absorption being exercised by dead animal textures as well as the living, may be correctly termed the inorganic, in contradistinction to the lymphatic absorption.

Gases, and thin fluids, together with the matters they hold in solution, permeate moist animal textures. Two kinds of gases in contact with the two surfaces of a moist animal bladder, one being within it and the other external to it, each permeate the bladder till they are equally mixed. The bladder having been previously dried and then moistened does not prevent this process taking place. A gas will permeate a moist bladder, to be absorbed by a fluid within it. This explains how it is that gaseous matters can enter into the blood during respiration, without the globules of the blood escaping.

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[*] Froriep's Notiz. xiv. p. 200.

[†] On the subject of absorption by the capillaries and veins, consult Westrumb, Physiolog. Untersuch. über die Einsaugungs-kraft der Venen. Hannover, 1825. Tiedemann und Gmelin, Versuche über die Wege, auf welchen Substanzen aus dem Magen and Darmkanal ins Blut gelangen. Heidelb. 1820. Seiler und Ficinus in Zeitschrift für Natur-und Heilkunde, ii. 378. Jaeckel, De absorptione venosa. Vratislav, 1819. Lebkuckner, Diss. utrum per viventium adhuc animal. membran. aq. vasor. parietes mater. ponderab. illis applicat. permeare queant, nec ne. Tüb. 1819. Wedemeyer, über den Kreislauf. Hannover, 1828, 421. Schabel, de effect. veneni rad. veratri albi et hellebori nigri. Tub. 1819. Schnell, Diss. sist. hist. veneni upas antiar. Tub. 1815. Tübing. Blätter. 3. 1. 1817.

The gaseous matters permeate the membranes of the lungs, and are dissolved in the blood circulating in the numerous capillaries which traverse these membrances, by virtue of the invisible porosity of the coats of the vessels, which, nevertheless, have no openings large enough to admit the red particles of the blood. If a piece of moist bladder is tied over a bottle completely filled with water, so that the bladder is in contact with the surface of the water, and if some salt is then strewed over the outer surface of the bladder, it is dissolved by the water which permeates the pores of the bladder, and thence is imparted to the water in the vessel. The primary cause of imbibition, or the permeability of animal tissues, is therefore the tendency which substances have to diffuse themselves uniformly in the fluid in which they are dissolved. A salt in solution has a tendency to diffuse itself through any other fluid with which it is miscible. Salt water and water, for example, when in contact become uniformly mixed with each other. Animal tissues owe their softness to the watery fluids which they contain, and which fill their pores. Any matter in solution, therefore, which comes in contact with them will tend to diffuse itself in the fluids of the pores, and again, through the medium of these pores, with fluids in contact with the opposite side of the membrane, until the distribution of the matters dissolved is uniform in the two fluids which the membrane separates. There are, however, particular circumstances under which the process of imbibition is accelerated by attraction, or by the action of capillary tubes. The latter is the case when a dry animal texture is moistened, for there the capillary attraction of the empty pores must favour the entrance of the fluid. The influence of attraction in modifying imbibition is displayed in the phenomena of endosmose and exosmose, first discovered by Parrot, and farther investigated by Porret, Dutrochet, and others. If a solution of any salt, or of sugar, is poured into a glass tube closed below by a piece of bladder, the particles of the solution permeate the pores of the bladder, but do not pass through it. If the tube thus filled is placed in a vessel containing distilled water, the fluid gradually rises, and sometimes to the extent of several inches, within the tube, while by proper tests it is found that at the same time a portion of the solution has found its way from the interior of the tube to the water external to it. The elevation of the level of the fluid in the tube continues till the two fluids are homogeneous. If the tube contains water, and the exterior vessel the saline solution, the water sinks in the tube. If both vessels contain solutions of different salts, but of the same density, the level of the fluids does not alter, but the two salts become equally mixed. If, on the contrary, one solution is more concentrated than the other, the quantity of the more concentrated one becomes increased. The same phenomena are observed when, in place of the bladder of an animal, porous mineral substances are used. Two explanations of the phenomena have been given. The first, which was offered by Magnus and Poisson, is, that between the particles of a saline solution a compound attraction subsists, consisting of the mutual attraction of the salt and water, of the attraction between the individual particles of the water, and of that between the individual particles of the salt. This compound attraction is supposed to be more powerful than the simple attraction between the particles of water.* The second explanation is the following:—The animal bladder, inasmuch as it is porous, may be viewed as a system of capillary tubes exerting attraction on the fluids, which are tending through their medium to mix with each other. If, now, one of the fluids be more strongly attracted by the tissue of the bladder than the other, it will, of course, be longer retained in its passage through the pores; and while the level of the fluid which passes through more quickly will necessarily fall in the vessel that contains it, that of the slowly traversing one will rise until the increasing pressure of the rising column of water counterbalances the effect of the more powerful attraction.†

Dutrochet has named the phenomena which we have described "endosmose" and "exosmose," according as the quantity of the one or of the other fluid increases under different conditions. In the direct passage of matters in solution into the capillaries and the blood, endosmose without doubt takes place, and not merely simple imbibition. Dutrochet has demonstrated this by experiment. A portion of the intestine of a young fowl, half filled with a solution of gum, sugar, or common salt, and tied at both ends, was placed in a shallow vessel filled with water, when it soon became filled to distension. If, on the contrary, the intestine contained pure water, and was immersed in sugared water, it became gradually more lax, and the fluid in the intestine was afterwards found to contain sugar.‡

Dutrochet's hypothesis, that electric action is connected with these phenomena, has not been confirmed: nor does it constantly happen that the denser fluid attracts more of the thinner than the latter does of the former: in the case of gases especially, the contrary is sometimes seen to be the case. But the chemical constitution of the fluid, and its physical and chemical relation to the animal membrane which it permeates, seem to have an important influence on the phenomenon. Dilute alcohol kept in a bladder becomes more concentrated, the water alone evaporating;§ and it has been found that if a portion of the intestine of a fowl filled with a watery solution of acacia gum and rhabarbarin, and tied close, is laid in a vessel containing water, the intestine becomes distended, while the rhabarbarin exudes from it. Similar sacks filled with a weak solution of sulphate of iron, and laid in a solution of ferrocyanate of potash, became distended in consequence of the endosmosis of the water of the external solution, which at the same time acquired a blue colour from the salt of iron having passed through the membranes in an outward direction, while the absence of this colour in the fluid in the interior of the portions of gut proved that the salt of potash had not permeated them. The phenomenon of the endosmosis of gases, on which Dr. Faust* has instituted experiments, are very remarkable. A bladder half filled with atmospheric air being placed under a jar containing carbonic acid becomes more distended; and if the bladder which is placed in the carbonic acid gas contains hydrogen, it becomes distended to bursting. If, on the contrary, the jar contains the lighter, and the bladder the denser gas, the bladder becomes collapsed.(*a*)

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* Berzelius, loc. cit. p. 134.

† Biot, Experimental-Physik, translated into the German by Fechner, i. 384. See also Poisson, in Poggendorf's Annal. xi. 134. Fischer, ibid. 126. Magnus, ibid. x. 153; and Wach, Schweigg. Journal, p. 20.

‡ Dutrochet, L'Agent immédiat du mouvement vital. Paris, 1826. Nouv. Rech. sur l'endosmose. Paris, 1828. See also the article Endosmose in the Cyclopædia of Anatomy.

§ See experiments of Staples in Kastner's Arch. für Chemie, Bd. iii. H. 1—3, p. 282.

Time required for absorption by the capillaries.—I wished to know the time required for any substance to reach by the way of imbibition the superficial layers of the capillaries of a part which is not invested by epidermis, so as to enter the circulation. The delicate membrane which forms the villi of the intestines in the calf and ox contains capillary blood-vessels, although the villi themselves measure only $\frac{1}{130}$th of an inch in diameter. From this measurement we can conceive to what depth fluids must permeate to reach the capillaries of any membrane free from epidermis. Having put into a glass vessel with a very narrow neck some solution of prussiate of potash, I tied over it, in one experiment, the urinary bladder of a frog, in another the lung of the same animal, then with a hair-pencil applied to the surface of the soft membrane some solution of a salt of iron (the muriate), and at the same moment inverted the glass, so that the solution of prussiate of potash came in contact with the inner surface of the membrane. A second of time had not elapsed when a pale blue spot formed, and soon became more distinct. It appears, therefore, that substances in solution permeate a membrane of the thickness of the stretched bladder of a frog in perceptible quantity within a second of time. The membrane forming the frog's bladder consists of several layers, and is very much thicker than the organised membrane which forms the intestinal villi. We may therefore safely admit, that substances in solution permeate, in quantity sufficient to be detected, a membrane not covered by epidermis, so as to reach the first layer of capillaries, and thus to enter the circulation in a shorter time than a second. Now the blood, according to Hering's calculation, circulates through the whole body in half a minute, and, according to others, in from one to two minutes; consequently we may suppose that a minute quantity of any substance in solution, which comes into contact with a membrane free from epidermis, may be distributed through the circulating system in the period of from half a minute to two minutes.

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* Amer. Med. Journ. vol. vii. Froriep's Not. N. 646.

(*a*) Dr. J. K. Mitchell, at the time (1830) lecturer on Chemistry in the Philadelphia Medical Institute, and now Professor of the Practice of Medicine in Jefferson Medical College, instituted a course of experiments still more varied on the subject, which he entitled, "*On the Penetrativeness of Fluids,*" (*Am. Journ. Med. Scien.* Vol. VII.) Subsequently, in 1833, he renewed his inquiries, which were published in the *Am. Journ.* Vol. XIII, under the head of the *Penetration of Gases.* He performed at this time numerous experiments on the penetration of gases through wet and recent animal tissues, as well as inorganic membranes; and has thus put on record much valuable matter, and furnished at the same time pregnant suggestions for the physiologist, in his investigations into absorption, respiration, secretion and nutrition.

Action of poisons.—The narcotic poisons act, it is true, by abolishing the nervous energy, but, when applied locally to the nerves, their effects are only local. I held the nerve of a frog's leg, which was separated from the body, in a watery solution of opium for a short time, and that portion of the nerve lost its irritability, *i. e.* its property of exciting twitchings of the leg when it was irritated; but, below the part that the poison had touched, the nerve still retained this function. Opium, therefore, produces a change in the nervous matter itself; but the influence is local, and is not propagated through the nerves, so as to produce general poisoning. Frogs are very sensible to the effects of opium; and nevertheless, if the leg of a frog is separated from the body, the nerve only being left to maintain the connection, and is then placed in a solution of opium, and kept there for several hours, the animal suffers no narcotic influence; provided, however, that it is so confined, that in its struggles it cannot throw any of the fluid over its body. More recently I laid bare the ischiadic nerve in toads, and removed all the flesh of the thigh, leaving the leg and thigh connected to the trunk by means of the bone and nerve only. I then immersed the leg in a solution of the acetate of morphia, and in a concentrated solution of opium, and kept the animals thus for a considerable time. No general symptoms of narcotisation were produced; even at the end of many hours, the animals retained perfect power of motion and sensation in the rest of the body.

These experiments, as well as many others, instituted by well-known physiologists, prove that, before narcotic poisons can exert their general effects on the nervous system, they must enter the circulation. Dupuy and Brachet indeed maintain that animals cannot be destroyed by narcotic poisons introduced into the stomach, if the nervus vagus has been divided on both sides, or, at least, that they do not die so soon. But in thirty experiments on Mammalia, which M. Wernscheidt performed under my direction, not the least difference could be perceived in the action of narcotic poisons introduced into the stomach, whether the nervus vagus had been divided on both sides or not, provided the animals were of the same species and size.

The first facts in support of the correct theory of the action of narcotic poisons we owe to Fontana,* who instituted experiments with the poisons of the viper, ticanas, and laurel-berries, and with opium; and found that these and similar poisons did not produce their general effects unless they entered the circulation, and that, applied to the nerves, they exerted only a local influence on them. Sir B. Brodie† afterwards divided all the nerves of the anterior extremity in the axilla of a rabbit, and applied woorara poison to a wound in the foot of the same limb: the action of the poison was not prevented. He applied a strong ligature to the hind leg of a rabbit, excluding only the principal nerves, and then inoculated the leg with woorara; but no poisonous effects were produced until he loosened the ligature, when they immediately ensued. Wedemeyer[*] found that prussic acid, so strong that it proved fatal within a second when introduced into the eye and other parts of the body, produced no such rapid effect when applied immediately to the nerves. Emmert amputated the extremities of animals, leaving them connected with the trunk by the nerves only, and then introduced poison into the feet; no general symptoms resulted. He likewise applied the poison to the nervous trunks themselves, but without effect. C. Viborg[†] applied almost a drachm of concentrated prussic acid to the brain of a horse, laid bare by means of the trephine, without the slightest symptoms of poisoning being produced.[‡] Hubbard[§] has, it is true, seen prussic acid applied to the nerves, act rapidly; but he himself confesses that when he isolated the nerve by placing a card beneath it, the poison produced no effect.

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* On poisons.

† Phil. Trans. 1811, p. 178; 1812, p. 107.

The rapid action of the greater number of narcotic poisons is perfectly explicable by the facts above detailed respecting absorption by imbibition. Prussic acid, however, exerts its influence in a much shorter time than would be required for it to enter the circulation through the medium of the capillaries, which, as we have said, is half a minute, or two minutes. The spirituous solution of extract of nux vomica, also, introduced in small quantity into the mouth of a young rabbit, produces immediate death; whereas when applied to a nerve at some distance from the brain,—for instance, to the ischiadic nerve,—it produces no general symptoms. Concentrated prussic acid, also, as Wedemeyer observed, does not exert its poisonous influence when applied merely to a bare nerve. The rapid effects of prussic acid can only be explained by its possessing great volatility and power of expansion, by which it is enabled to diffuse itself through the blood more rapidly than that fluid circulates, to permeate the animal tissues very quickly, and in a manner independent of its distribution by means of the blood, and thus to produce the peculiar material changes in the central organs of the nervous system more quickly in proportion as it is applied nearer to it.

Passage of ingesta into the secretions.—The rapidity with which fluid matters are imbibed into the capillaries, and distributed through the body by the circulation, explains completely the quick reappearance in the urine of substances which have been taken into the stomach with the food, without the need of having recourse to the barbarous notion of secret passages existing between the stomach and kidneys. According to Westrumb, soluble salts find their way into the urine in from two to ten minutes after they are taken into the stomach; for, when this time had elapsed after his giving prussiate of potash to an animal, he was able to detect it in the urine which he collected immediately from the ureter. Stehberger's experiments, however, prove that the reappearance in the urine of substances taken with the food ordinarily requires a much longer period.

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[*] Physiol. Untersuch. über das Nervensystem und die Respiration; Hanover, 1817, p. 234.—Consult also Emmert, Tübing. Blätter. 1811, Bd. ii. p. 88. Salzb. Medic. Zeitung. 1813, Bd. iii. p. 62. Meckel's Archiv. i. p. 176. Schnell, Diss. Sist. Historiam Veneni Upas antiar. Tübing. 1815.

[†] Act. Reg. Soc. Med. Hafn. 1821, p. 240.

[‡] See Lund, Vivisectionen, pp. 103, 104.

[§] Philadelph. Journal, Aug. 1822.

Absorption of chyle.—The matters which pass by imbibition through the walls of the capillaries into the blood must, however, be in solution; they must not consist of globules. This condition alone shows that the digested matters, and the chyle which contains globules, cannot find their way by imbibition into the capillaries and the venous blood. Tiedemann, Gmelin, and Mayer, have, it is true, observed streaks of chyle in the intestinal and portal veins. But the chyle could not have entered the blood through the walls of the capillary vessels; for if that were the case, the corpuscules of the blood in the capillaries would likewise be able to escape from them. Perhaps the streaks of chyle observed by these physiologists were derived from the communications which are supposed, although not yet proved, to exist between the lacteals and the small veins.

Endosmosis, however, *does not explain the absorption of all fluids* by the animal tissues. If the fluids of the tissue itself are more concentrated than those to be absorbed, such as fluids collected in the pleura, or lungs, the passage of the external fluids into the parenchyma will, according to the laws of endosmosis, take place more readily than the passage of the fluids of the tissue outwards. But if, on the contrary, the external fluid is equally concentrated with that contained in the tissue, the two fluids ought, according to the laws of imbibition, to pass through the membrane in both directions with equal rapidity, so that the quantity of both of them would remain the same; and if the fluid of the tissue is the less concentrated of the two, it will exude in greater quantity than the external fluid will be absorbed, so that the quantity of the latter will be increased. Imbibition, therefore, does not explain the diminution of the quantity of fluids by absorption, but only the mingling of them, as in the case of poisons applied to the surface of the body, &c. For a collection of fluid in the pleura, containing albumen and salts in the same state of concentration as these substances exist in the blood, would not be diminished in quantity by imbibition alone; there would be merely an interchange of the saline matters contained in the external fluid and in the blood, while the bulk of the former would remain the same; and, if the saline ingredients were in a more concentrated state in it than in the blood, its quantity would even become increased.

The removal of collections of fluids by absorption must be effected in many cases either by means of the lymphatics, independently of imbibition into the capillaries, or we must suppose that the suction of the venous blood towards the heart assists the absorption by the capillaries. It is possible that the process of endosmosis may be modified by a peculiar attraction exerted by the tissues on the fluids circulating in them; an attraction, by the agency of which the fluids in the tissues may be retained while the external fluid is absorbed, so that absorption merely, and not an interchange of fluids, as is the case under ordinary circumstances, is the result. Water, for example, would have a tendency to diffuse itself in the blood of the capillaries; but the blood being under the influence of the mutual vital process which is going on between it and the capillary vessels, would have no tendency to diffuse itself in the water. The red particles of the blood have, as we have already seen,* a great affinity for water, and in their passage through the capillary vessels they may contribute to cause its absorption.

Absorption by organic attraction.—The question whether the blood in the capillary vessels, or these vessels themselves, exert on certain substances an attraction different in its nature from any determined by physical laws, is quite distinct from the one above discussed. There is only one part of the body in which this kind of attraction certainly exists, and that is the capillary system of the placenta. The existence of lymphatics in the placenta and umbilical cord being quite problematical, the transmission of nutritive fluids from the mother to the child must be effected by means of the capillary vessels of the placenta. There is no direct communication between the vessels of the mother and those of the fœtus: the sole mode in which the uterine arteries terminate is by becoming continuous with the radicle uterine veins; and, on the other hand, the fœtal arteries of the placenta have no other mode of termination than in the commencing fœtal veins of the same part. Weber† has given a very interesting description of the mode in which the placenta and uterus are connected. The finest ramifications of the placental vessels are distributed in the tufted processes on the maternal surface of the placenta. The arteries ramify in the tufted villi, and terminate at the extremities of the villi by direct inosculation with the radicles of the placental veins. Bundles of these tufts of villi project into the cavities of the large veins, in which the maternal blood flows on the inner surface of the uterus. From this arrangement of the tufts, and from the delicacy of the coats of the uterine veins, the fœtal blood circulating through the capillaries of the placental tufts is freely exposed to the action of the venous blood of the mother, and probably attracts from it some of the matters dissolved in it.

In the endosmosis which takes place between the fœtal and maternal blood, more matter undoubtedly is received by the fœtal blood than is given in exchange by it to the blood of the mother. It is an organic and vital endosmosis totally different in the laws which regulate it from the chemical process of imbibition described by Dutrochet. In ruminating animals the tufts or villi of the cotyledons of the ovum are not imbedded in the veins of the uterus, but, like roots in the ground, in sheath-like cavities, or tubes, hollowed in the substance of the uterus. All these excavations in the uterus are lined with capillaries of the maternal vessels; while the capillaries of the fœtus, which have no communication with those of the mother, are distributed upon the tufts of the cotyledons. Here the matters which are to be absorbed by the capillaries of the fœtus must first be secreted by those of the mother.

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* See pages 148-9.

† Hildebrandt's Anatomie, Bd. iv. p. 496.

Does the action of the heart aid absorption?—It is still matter of doubt whether the absorption of fluids into the capillaries by means of imbibition is aided by the motion communicated to the blood in the veins, and so to that in the capillaries also, by the sucking action which the heart exerts in the dilatation of its cavities. The motion of the blood, however, must be so far favourable to imbibition, as that it removes what has already been absorbed, and thus renders constant the cause of the endosmosis,—namely, the tendency of substances to diffuse themselves through fluids till they are equally distributed. If the same portion of blood were constantly exposed to the same part of the tissues, imbibition would after a time necessarily cease.

Influence of galvanism on imbibition.—Fodera* has observed that absorption, or imbibition, is accelerated by the action of galvanism. He injected prussiate of potash into the pleura, and sulphate of iron into the abdomen. Usually five or six minutes elapse before these two substances combine; but their combination was instantaneous when a slight galvanic current was passed through the diaphragm. The same phenomenon is said to occur when one fluid is introduced into the urinary bladder, and the other into the abdomen, or one into the lung, and the other into the pleura. The nerves have no influence on inorganic imbibition; there was, in my experiments, no perceptible difference in the absorption of poisons whether the nervus vagus had been divided or not.

Changes produced in the matters absorbed.—Matters which find their way from the intestines into the circulation by permeating the coats of the capillaries, do not pass directly from the intestinal veins into the vena cava; they circulate through the liver before reaching the general circulation. Magendie has observed, that in their transit through the liver the properties of many substances are altered. Thus, if a gramme† of bile, or a considerable quantity of atmospheric air, is injected into the crural vein, immediate death is the consequence; while, if they are injected into the vena portæ, the animal suffers no ill effect. Many substances undergo a change in the intestines themselves. Thus the poison of the viper, when taken into the stomach, produces, according to Redi and Mangili,‡ and Dr. Stevens,§ no poisonous effects; and the saliva of hydrophobia, according to Coindet,‖ does not exercise its infectious property when taken into the alimentary canal.

Effect of plethora on absorption.—Magendie has observed that distension of the blood-vessels, with an excess of fluid, diminishes the activity of absorption. By the injection of water into the veins, the absorption of foreign substances by the membranes with which they were brought into contact was prevented; but after taking some blood from the animal, absorption commenced with the usual phenomena. Venesection, on the contrary, accelerated the process; so that phenomena, which ordinarily did not ensue till after two minutes, appeared in half a minute.

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* Journ. de Physiol. iii. p. 35.

† About 15½ grains avoirdupois.

‡ Meckel's Archiv. iii. 1817, p. 639.

§ On the Blood, p. 137.

‖ Froriep's Notiz. 1823, Sept. 170.

Absorption by the skin.—Absorption is most rapid from the mucous membranes, from serous membranes, and from wounds; it is much slower from the skin covered with epidermis. The most external layer of the organised cutis seems indeed to possess a very feeble absorbent power: this may perhaps arise from its secreting horny matter. Colouring matter, consisting of granules or grains of powder from an explosion, having found their way into cracks of the skin, remain during the entire life without being dissolved or absorbed. Nitrate of silver given internally for a considerable time, imparts a blackish-slate colour to the skin, probably from a chemical combination being formed between the silver and the animal matter. The skin covered with epidermis, however, is certainly endued with an absorbing power; but the substances to be absorbed must be either in solution, or readily soluble in the animal fluids. The subject of absorption by the skin is important, both on account of the frequency with which foreign substances come into contact with it, and from its being adapted to the application of medicinal substances. Seiler and Ficinus found that when the feet of horses had been moistened with solution of oxide of lead in liquor potassæ, this substance could be detected in the blood and chyle.*

All metallic preparations rubbed into the skin have the same action as when given internally, only in a less degree. Mercury applied in this manner cures syphilis, and excites salivation; tartrate of antimony, according to Letsom and Brera, excites vomiting; and arsenic produces its poisonous effects. Vegetable matters, also, if soluble, or already in solution, give rise to their peculiar effects through the medium of the skin. Haller states that white hellebore laid upon the abdomen excites vomiting, and that violent purging is produced by washing the feet with a decoction of either the white or the black hellebore. Sabadilla seeds applied to the skin were found by Lentin to excite most violent cramps, and when rubbed on the abdomen to cause purging. Cantharides applied to the skin excite strangury; and narcotics thus applied induce the usual symptoms. Camphor, Magendie says, can be detected in the vapour expired from the lungs; oil of turpentine, in the urine by the violet smell which it gives to that fluid; mercury, in the blood, saliva, urine, and milk, according to Bloch, Autenrieth and Zeller, and Cantu, and in the bones also, according to Fricke;† prussiate of potash, rhubarb, and madder, in the blood, urine, &c.; each of these substances having in the respective cases been applied to the skin. But the action of all medicinal substances and poisons applied to the skin, is much more powerful if the cuticle has been previously removed.

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* On this subject consult Westrumb, Meckel's Archiv. 1827; Sewall, ibid. ii. 146. And Dr. Madden's Experimental Inquiry into the Physiology of Cutaneous Absorption, Edinb. 1835.

† Horn's Archiv. 1826, 459.

It has long been a contested question whether the skin covered with its epidermis has the power of absorbing water, and it is a point difficult to determine, because the skin loses water by evaporation.

The epidermis is certainly hygroscopic, and swells when placed in water. The experiments of Falconer, Alexander, and others, which consisted in weighing the body and the water in baths, appear to me unworthy of dependence. Seguin* and Curriet could discover no increase of weight when the whole or part of the body was immersed in water; and those experiments in which colouring matter or prussiate of potash dissolved in the water of a bath could afterwards be detected in the urine, by no means prove that the water was absorbed. Saline substances can permeate a membrane both sides of which are in contact with water, without the level of the water on either side undergoing any change.

M. Edwards‡ has proved most clearly that this absorption of water by the surface of the body, takes place in the lower animals very rapidly under certain circumstances. Not only frogs, which have a thin skin, but lizards, in which the cuticle is so very much thicker than in man, after having lost a great part of their weight by being kept for some time in a dry atmosphere, were found to recover both their weight and plumpness very rapidly when immersed in water. When the tail, merely, the posterior extremities and hind part of the body of the lizard, were immersed, the water absorbed was distributed throughout the system. M. Edwards thinks it impossible not to attribute this property to the skin of man, if the scaly skin of the lizard possesses it. In M. Seguin's experiments there was a loss of weight during the immersion in the bath, but less than takes place during the same period in the air. This result M. Seguin attributed to an arrest of the cutaneous transpiration while the pulmonary exhalation was uninterrupted. M. Edwards, however, suggests that the cutaneous transpiration was not arrested, but merely balanced by absorption of water from the bath. It is certain, that in air loaded with moisture (for example, in vapour baths), the exudation from the surface of the body is even greater than under ordinary circumstances, but it is difficult to prove that the same process goes on during immersion in water. However, whether this explanation of M. Seguin's experiments be admitted or not, we have some direct experiments by Dr. Madden§ and M. Berthold, which seem to prove the possibility of absorption of water by the skin. Dr. Madden having ascertained by means of an accurate balance the loss of the weight by cutaneous and pulmonary transpiration, that occurred during half an hour in the air, entered the bath, and remained immersed during the same period of time, breathing through the medium of a tube, which communicated with the air exterior to the room. He was then carefully dried and again weighed. Twelve experiments were performed in this manner; and in ten there was a gain of weight, varying from 2 scruples to 5 drachms and 1 scruple, or a mean gain of 1 drachm, 2 scruples and 13 grains. The loss to the air during the same length of time (half an hour) varied in ten experiments from 2½ drachms to 1 ounce 2½ scruples, or in the mean was about 6½ drachms. So that, admitting the supposition that the cutaneous transpiration was entirely suspended, and estimating the loss by pulmonary exhalation at 3 drachms, there was in these three experiments of Dr. Madden an average absorption of 4 drachms, 1 scruple and 3 grains, by the surface of the body during half an hour. In two experiments, however, Dr. Madden found an absolute loss of weight, which in one case far exceeded the loss that ordinarily occurs in the air. In four experiments performed by M. Berthold,* the gain in weight was much greater than in those of Dr. Madden; but as the latter gentleman states more precisely the precautions taken to avoid error, his results seem to be entitled to greater consideration.

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* Ann. de Chimie, t. xc. 185; t. xcii. 33.—Meckel's Archiv. iii. p. 385.

† Med. Reports, ch. xix.

‡ On the Influence of Physical Agents on Life, pp. 181—189.

§ Loc. citat. p. 58.

The absorption of different kinds of gas by animal tissues, as in the process of respiration, and even by the skin itself, is placed beyond doubt by the experiments of Abernethy, Cruikshank, Autenrieth, Beddoes, and Collard de Martigny. In these cases, of course, the absorbed gases combine with the fluids, and lose the gaseous form. Several physiologists have observed an absorption of nitrogen by the skin. Beddoes says that he saw the arm of a negro become pale for a short time when immersed in chlorine; and Abernethy observed that when he held his hands in oxygen, nitrogen, carbonic acid, and other gases contained in jars over mercury, the volume of the gases became considerably diminished.

Interstitial absorption.—It is still a matter of doubt whether the absorption which goes on in the substance of the different textures of the body is chiefly performed by the blood-vessels, or by the lymphatics. In many parts, however, in which the existence of lymphatics has never been demonstrated,—for example, in the bones,—there is marked evidence of absorption going on.

In many other cases in which matters are absorbed from parts known to possess lymphatics as well as blood-vessels, it is quite uncertain into which order of vessels these matters are first received. This is the case in the following instances:—The reabsorption of the colouring matter of the bile deposited in the different tissues in jaundice, and the absorption of accumulated secretions, such as bile and urine, into the circulation; the wasting of the thymus gland during the period from infancy to the twelfth year; the disappearance of the fat from the body generally in persons fasting, and in consumptive persons also, after great losses of the fluids of the body, and in animals during hybernation; and the frequently rapid disappearance of warts from the fingers. These cases of absorption are not all of the same kind. The true interstitial absorption of organised tissues, in which the particles of the tissue which fill the meshes of the capillary network are removed, must be distinguished from the cases of the absorption of fluids, which do not form part of the tissue, and have therefore no mutual vital action with the blood-vessels. In the process of interstitial absorption, as it occurs in the atrophy of the tail of the tadpole, and of the pupillary membrane in the fœtus, and in the development of cells in the bones, the most essential circumstance, perhaps, seem to be a solution of the particles which occupy the meshes of the capillary system. The matter when dissolved may be removed by imbibition into the currents of blood, or, except in the case of the bones, by absorption by the lymphatics. Of all organised parts, the bones present the phenomena of interstitial absorption in the most remarkable degree; their cells are developed in the child long after the bone is formed, and increase in size by the agency of the same process. The diploe of the cranial bones disappears in old age, and the bones become thinner. The frontal and sphenoidal sinuses are developed in the period of youth. Parts, however, which are not organised, or rather not vascular, but are only in connection with an organised matrix,—for example, the roots of the teeth,—are also subject to absorption. The roots of the first teeth disappear at the time of the change of the teeth; and Soemmering* has observed that they become soft, probably in consequence of solution of their component matter. In caries, also, which depends on an abnormal combination of their components, the teeth are acted on by the fluid of the mouth and softened. It is still unknown whether portions of dead bone which remain long in contact with living textures, diminish in size.†

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* Müller's Archiv. 1838, p. 177.

When, in consequence of diseased states of the blood, of paralysis, or other causes, nutrition is less active, the interstitial absorption is no longer counterbalanced, and the part wastes. Whether in phthisis the muscular fibres themselves waste, or merely the cellular membrane in their interstices, is uncertain; thin muscles, however, such as the platysma myoides, and some muscles of the external ear, seem really to waste. In paralysis the wasting of the muscles is more frequent; and Schroeder van der Kolk has even observed their conversion into fat. Cartilage, bone, brain, and nerves, according to Desmoulin's and Schroeder's researches, do not waste in phthisis. When the cause of atrophy is general, the tissues are absorbed in the following order; fat, cellular tissues, muscles, bone, cartilage, and tendon. Long-continued pressure, by putting a stop to nutrition, may cause every tissue to be absorbed. The mode in which pressure acts in causing the absorption of bone, is, however, a problem still requiring solution; for, if the cessation of nutrition in consequence of the pressure were the sole cause, the articular heads of the bones of the lower extremities ought also to be absorbed. Perhaps a tumour affecting all surrounding parts—such as an aneurism, or fungoid tumour—excites inflammation of the bone, as well as of other parts; and bone when inflamed becomes softened, and is consequently more readily susceptible of absorption when its nutrition happens to be interrupted by pressure. Caries, however, is not produced in these cases.* It is a well-known fact that iodine favours the wasting and absorption of organised tissues.

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* Vom Bau des Menschlichen Körpers, i. § 226, 233.

† The recent observations and experiments of Miescher (De inflam. ossium, eorumque anatom. generali.—Berol. 1836), and of Mr. Gulliver (Med. Chir. Transact. v. xxi.), are unfavourable to the opinion that dead portions of bone are absorbed.

b. Of exhalation and exudation.

Many matters dissolved in the animal fluids, particularly foreign substances which have been taken up into the circulation, and which are then distributed through the body with the blood in their original state, or more or less altered, are afterwards eliminated from the system by the process of imbibition and endosmosis. Prussiate of potash, having entered the circulation by endosmose, permeates the tissues which form the surfaces communicating with the exterior, according to the same laws, and becomes mingled with the natural secretions. In this way it soon appears again in the most various secreted fluids; in the urine, for instance, it may be detected, according to Westrumb, in from two to ten minutes after its introduction into the body. The blood impregnated with prussiate of potash, and the fluid contained in the cavities of the secreting organ,—for example, the urine in the *tubuli uriniferi* of the kidney,—are able, in accordance with laws purely physical, to impart to each other the substances that they contain in solution until these substances are equally diffused in both. In jaundice, almost all the internal organs, as well as the secretions, become impregnated with the colouring matter of the bile which is contained in the serum of the blood.

Those natural or accidental ingredients of the blood which are capable of assuming the gaseous form, unless they are retained by some special attraction exerted on them by the tissues, may evaporate from the free surfaces of the membranes of the body.

When pressure favours their passage through the pores of the animal membranes, even fluids must, in accordance with physical laws, force their way into the free cavities filled with gas or vapour; —hence the effusion of fluids in the animal body after death as the effect of mere gravitation; serum, at first pure, afterwards with the colouring matter of blood dissolved in it, permeates the tissues, and may collect in the different cavities; the bile exudes from the gall-bladder, and colours the parts which are in contact with it. During life, absorption effected by an attraction of a vital nature, counterbalances this transudation of fluid through the membranes of the body; but, in disease, different causes destroy the balance of the two processes, and then the water, with the animal matter and salts dissolved in it, collects in the cavities of the body and in the cellular membrane, and gives rise to the appearances of anasarca or œdema, and albuminous urine. Obliteration of the great venous trunks of the viscera or of the extremities, gives rise to exudation of albuminous fluid into the surrounding serous sacs or into the cellular membrane, particularly of the inferior extremities; and artificial dropsy of the cellular membrane may be produced, as Bouillaud has shown, by tying the great venous trunks. The dropsies occurring in consequence of degeneration of the viscera, may also possibly be partly dependent on the circulation through the viscera being obstructed. The exudation of the fibrinous fluid in inflammation might be explained in the same way; but the quality of the exuded matter depends on other causes.

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* On this subject consult Schroeder van der Kolk in Luchtmann, De absorptionis sanæ et morbosæ discrimine. Traj. ad. R. 1829.

The foregoing observations would seem to show that the exhalation of vapour, and exudation of fluid, are, even in the living body, the result of the purely physical laws of imbibition, endosmosis, and pressure; but that is not the case. If exudation during life were solely under the influence of these physical laws, all the ingredients of the fluids would escape equally; but the matter which permeates the tissues, and is exhaled or exuded, often consists of a part only of the substances which are contained in solution in the blood. Thus, in inflammation, the matter which exudes through the membranes, is the fibrin which the serum of the blood holds in solution; while, on the contrary, in dropsies,—such as are produced, for example, by obstruction to the return of venous blood,—the fibrin does not exude; the exudation is merely an albuminous fluid. There must, then, under ordinary circumstances, be some force in action which prevents the escape of fibrin from the vessels, but which in inflammation is rendered inert; and this force must be an affinity or attraction subsisting between the parenchyma and the fibrin, but not between the parenchyma and the albuminous serum, which therefore in anasarca is allowed to escape. At the commencement of inflammation, as observed in a wound, or after the application of a blister, serum merely is effused; when the inflammation becomes more violent, the fibrinous part of the blood also exudes.

It is most probable that there are similar differences in the exhalation of fluids in the gaseous form, for instance, from the skin; and that not every part of the fluids of the body which is capable of assuming the form of vapour, is really exhaled from the surface of the membranes.[*]

Secretion.—The elimination of many substances from the blood cannot be explained according to the laws of endosmosis. The urea, for example, which has been proved to exist already formed in the blood itself, is nevertheless excreted by no other part of the body than the kidneys.

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[*] M. Magendie (*Leçons sur les Phénomènes physiques de la Vie*, Paris, 8vo. tt. ii. and iii. and *Comptes Rendus*, 1838) states, as the result of numerous experiments, that when water, or a substance which deprives the blood of its property of coagulating spontaneously, is injected into the vessels of an animal, or when the blood is extracted, robbed of its fibrin by stirring, and then restored to the vessels, effusions of serum or blood, and congestions take place in different parts of the body, but particularly in the lungs. This accords with what is observed in many diseases in the human subject, in which the blood is known to be in a state of diminished coagulability; but it does not, as M. Magendie supposes, afford an explanation of all the local inflammations that occur in the different febrile diseases.

Other excretions, derived from the blood, are formed only under certain local conditions. This is the case with the menstrual flux, which, according to the observations of Lavagna, Toulmouche, Brande, and myself, contains no fibrin; the clots which form in it are soft, and consist principally of red particles alone. Brande is certainly wrong in saying that the menstrual fluid is merely a concentrated solution of the red colouring matter of the blood; I have found red particles in it perfectly unchanged in appearance. It must therefore be supposed that, at the period of menstruation, the texture of the vessels of the uterus becomes so loose as to allow the escape of the red particles. There are no open mouths of veins in the uterus any more than in other parts of the body.

In the cases also in which the blood itself escapes slowly from the surface of membranes, by what is called exhalation, secretion, or "diapedesis," there is more than a simple secretion or transudation; the coats of the vessels must be changed in texture, and in many cases,—as for example, in hæmoptysis and in the bloody expectoration which accompanies inflammation of the lungs,—if not in all, there is rupture of the minute vessels or capillaries. The observations of Wedemeyer,[*] however, render it probable that, under particular circumstances, the colouring matter of the red particles may, even in living animals, be dissolved in the serum, and thus give rise to a coloured effusion. Having injected a considerable quantity of warm water into the veins of horses, he found that exudation of serum of a red colour, took place from the nostrils, and into the abdominal cavity. The colouring matter of the red particles is, it is known, soluble in water; and in scurvy, purpura, and after the bite of poisonous snakes,[†] it seems to be dissolved in the serum. A certain talented physician supposes the exhalation of blood or "diapedesis," of which we have spoken above, to be a mere exudation of a solution of colouring matter without any entire red particles. This is a difficult matter to prove, and until proved cannot be admitted as a fact. Even the bloody appearance of the serum of the blood in scurvy may arise, not from cruorine being dissolved in it, but from its containing a few red particles diffused through it, which is very likely to happen when blood does not coagulate firmly.

The globules of secreted fluids must be formed at the moment that the secretions are separated from the blood; they cannot have passed entire through the coats of the vessels. The globules of pus, for instance, which are larger than the red particles of the blood, and in part, according to Weber, twice as large, cannot be those bodies merely changed in some way. They must either be particles of the tissue separated from the suppurating surface, or they must be formed at the moment of the elimination of the secretion, as the observation of Brugmans and Autenrieth, that pus, when first formed, is a thin and clear fluid, would seem to indicate. The elimination, by the kidneys, of globules of pus which had found their way into the blood, is quite an impossibility; the proximate components only of the pus in a state of solution can be eliminated from the blood, the globules must be formed from these components afterwards. With the exception of the oil globules of the chyle and milk, the microscopic bodies contained in the different secretions seem to be merely particles of epithelium detached from the mucous surface, and mixed with the secreted fluids. The bodies having all the characters of pus globules, which are found in the fluids secreted from all mucous membranes when suffering under inflammation or mere irritation, would likewise appear to be formed by the cells of epithelium undergoing a morbid change during their period of development. M. Henle, indeed, regards them as cells of epithelium, of which the development has been merely arrested at an early stage. The origin of the similar pus-like bodies which are excreted with the urine and contribute to render it turbid in many affections of the kidney, and particularly in inflammatory states of that organ, is most probably the same, they being formed in the urinary canals in the place of the normal epithelium.* The relation which exists between the particles of epithelium, mucus, and pus, and the mode of their formation, has been more fully considered in the chapter on the Growth of the Tissues.

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[*] Ueber den Kreislauf. Hannover, 1828; p. 463.
[†] Autenrieth's Physiol. ii. 155.

SECTION III.

OF THE LYMPH AND THE LYMPHATIC VESSELS.

CHAPTER I.

Of the Lymph.

The *lymph* is the fluid contained in the lymphatic vessels; its appearance, as observed by Professors Wutzer and Nasse, and myself, is that of a transparent, pale yellow fluid; it has generally no tint of red, unless some of the red particles of the blood are accidentally mixed with it. In the frog it is perfectly transparent, and has not even a yellowish tint. Lymph is devoid of smell, is slightly alkaline, and has a saline taste. On examining the lymph in a human subject, exuded from a wound in the dorsum of the foot, I perceived, through a microscope, that, although a clear transparent fluid, it contained a number of colourless globules, which were much smaller and much fewer in number than the red particles of the blood.

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* See Vogel, Uber Eiter, Eiterung, und d. verwandt, Vorgange, Erlangen, 8.—Henle, Müller's Archiv. 1839. Jahresbericht, p. xviii. et sequent. and Hufeland's Journal, May, 1838; and Gluge, Anatomisch. Mikroskop. Untersuch. Minden, 1838.

These globules were visible even after the lymph had been coagulated. The coagulation consists of a white fibrous tissue, quite homogeneous, slightly transparent, and, as far as could be observed, did not consist of globules. These observations prove, that, although the lymph really contains globules, the fibrinous part exists in a state of solution. The lymph of the intestines, chyle, when it contains matter just absorbed from the digested food, is always more or less turbid, and has a yellowish gray or whitish colour, arising from the presence of a great number of globules: it is then called *chyle.*

Analysis of lymph and chyle.—The occurrence, says Dr. Baly, of a similar case to that above-mentioned, at Halle, has afforded to MM. Marchand and Colberg the opportunity of analysing chemically lymph of the human subject. In its general characters it resembled that described by Professor Müller, was strongly alkaline, and contained 3·074 per cent. of solid matter. In 1000 parts, 5·20 were fibrin; 4·34 albumen; 3·12 osmazome and loss; 2·64 oily and crystalline fatty matter; 15·44 chlorides of sodium and potassium, carbonate and lactate of an alkali, sulphate of lime, phosphate of lime and oxide of iron, and 969·26 water.*

The following is the composition of the lymph of the horse, according to Lassaigne's analysis:—

Water,	92·500
Fibrin,	0·330
Albumen,	5·736
Chlorides of sodium and potassium, with soda and phosphate of lime,	1·434
	100·000

Tiedemann and Gmelin state that the lymph contains, besides the above ingredients, salivary matter, osmazome, carbonates, sulphates, muriates, and acetates of soda and potash, with phosphate of potash.

The chyle differs from lymph in several particulars. It contains uncombined fatty matter which is not present in lymph. The proportion of the solid ingredients is greater in the chyle; Tiedemann and Gmelin obtained 0·37 parts of dry fibrin from 100 parts of chyle taken from the lacteals of the mesentery of the horse, while from the same quantity of lymph from the lymphatics of the pelvis they obtained only 0·13 parts. The chyle also contains more globules than the lymph, and is more opaque. The globules of the lymph are very few in number, and hitherto have been quite overlooked; Dr. H. Nasse and I have, however, seen them in the lymph of man, and I have seen them repeatedly in the lymph of frogs. It appears, also, that hitherto human lymph had never been examined. The fluid which Soemmering took from "varices" of lymphatic vessels, did not coagulate, and could not have been lymph.

The *lymph of frogs* recently caught contains, very scantily diffused in it, globules, which are about one-fourth the size of the red particles of the frog's blood. They are globular, while the red particles of the blood are elliptic and flattened. In dividing the skin of the frog's thigh, blood-vessels are necessarily cut; hence some of the elliptic particles of the blood will appear in the lymph when examined with the microscope; their number, however, is so small that they do not prevent the lymph from being perfectly clear and colourless.

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* Müller's Archiv. 1838, p. 129.

The lymph of the frog, which may be thus easily obtained, agrees so nearly with that of man, that we can at any time demonstrate at lecture the principal qualities of this fluid.

Hitherto no medical man could be upbraided if he had never seen lymph, although it is so much spoken of by pathologists and physicians. They have, indeed, been so ignorant of its nature, that the name of lymph has been given to very different fluids. Not merely exudations containing fibrin and albumen, but even the secretions of sores and puriform matters, and especially all matters the nature of which was not exactly known, have been called lymph.

The lymph globules vary very much in size, but the nuclei maintain in all nearly the same dimensions. These observations render it probable that the globules of the lymph are cells or vesicles gradually developed around a nucleus. The observation of M. Weber, which the translator can confirm, that they are elastic, and like the red particles of the blood undergo changes of form when they meet with obstacles to their course in the capillaries, is in favour of this opinion.

In the lymph of the frog it can be seen, even more distinctly than in that of man, that the clot is formed by the coagulation of the fibrin which was previously in solution, and that the globules of the lymph have no share in the act. The albumen of the lymph is coagulated by the ordinary reagents. It is remarkable that not only the lymph of the frog is rendered turbid by the addition of liquor potassæ in large quantities, and that albumen is immediately precipitated from the lymph of Mammalia on adding liquor potassæ; but that the albumen is precipitated even from a small quantity of the serum of the blood when liquor potassæ is added in large quantity. The liquor potassæ must, however, be quite concentrated.

Colour of the lymph and chyle.—The lymph seems to be colourless in most parts of the body under ordinary circumstances, but it has sometimes been seen of a reddish colour: both Magendie, and Tiedemann and Gmelin, observed this colour in the lymph of animals which had fasted; and in the lymphatics of the spleen, the lymph has frequently a red tint. This colour of the lymph of the spleen has been observed by Hewson, Fohmann, and Tiedemann and Gmelin. Seiler perceived it but rarely, and Rudolphi thought it was accidental. I have, however, repeatedly examined the spleen of the ox in the slaughter-house; and, among the numerous large lymphatic vessels running on the surface of the organ, have always found some in which the lymph had a dirty reddish colour. Hewson thought that this tint, which is very slight, was dependent on the presence of some red particles of the blood; but I am rather inclined to believe that it is owing to some of the colouring matter of the blood, in the highly vascular tissue of the spleen, having been dissolved by the lymph.

The chyle is almost always more opaque than the lymph of the same animal. The opacity of the chyle seems to be dependent on the globules that it contains. In Mammalia it is generally whitish, particularly after fat or animal food has been taken. In birds it is not white, and is more transparent. The chyle of the thoracic duct has, in the horse, a reddish tint, which is more rarely seen in other animals. When the red tint exists, it is deepened by exposure to the air.

Nature and source of the globules of the chyle and lymph.—The globules of the chyle of Mammalia, at least those of the rabbit, cat, dog, calf, and goat, which I have myself examined by means of the microscope, are not flattened like the corpuscules of the blood; they are globular. Prevost and Dumas found the diameter of the globules of the chyle to be $\frac{1}{7199}$th of an inch, that is, something more than one half the size of the red particles of the blood in man.*

The globules of the lymph must be derived either from particles cast off from the tissue of the organs during the process of absorption, or they must be formed in the lymph itself after it is absorbed. There are no proofs to show that the globules of the chyle are developed in the lacteals. If they are formed in these vessels, it must be in the network which is contained in the coats of the intestine, and from which the larger lacteals arise; for I have found the globules even in chyle taken from those lacteals which run on the surface of the intestines in the calf, in which animal these vessels, when filled with chyle, are very visible.

The presence of globules in the chyle might be explained even without the necessity of permeation of the coats of the lymphatics, and without pores existing, if Doellinger's hypothesis were adopted. Doellinger† supposes that the villi of the intestines are constantly undergoing solution in their interior, so as to form the chyle of the lacteals, while they are reproduced on their external surface by the aggregation and apposition of particles from the chyle contained in the intestines, in the same way as the germinal membrane of the embryo grows by the apposition of the particles of the yolk. There are facts, however, which render this hypothesis improbable. The absorption of milk, and consequently of globules into the blood, is rendered in some measure probable by a circumstance noticed by Schlemm. He has observed that, for a certain time after sucking, the blood of kittens is sometimes, but not always, of a yellowish red colour, and separates, when it coagulates, into a red clot and a milk-white serum. Rudolphi and I have verified this observation, and it has been confirmed by Mayer.‡ Rudolphi and Mayer assert that it is the case also in young puppies. I have made the experiment but once on puppies; the result did not confirm Rudolphi's and Mayer's assertion. It seems, then, that in young animals the globules which cause the white colour of the milk are really absorbed into the lacteals. All the milk, of course, cannot be absorbed in this way; for a portion, as Mayer remarks, is coagulated in the stomach. Kastner[*] repeated Schlemm's experiment without obtaining the same result.[†]

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* See E. H. Weber's remarks in Hildebrandt's Anat. t. i. p. 160.

† Froriep's Notiz. i. N. 2. ‡ Ibid. N. 536, 565.

CHAPTER II.

OF THE MODE OF ORIGIN AND STRUCTURE OF THE LYMPHATIC VESSELS.

a. Of the arrangement and structure of the radicle lymphatics.

The most important researches of earlier writers on the structure of the lymphatics, are contained in the collection of the works of Mascagni, Cruikshank, and others, edited by Ludwig. More recently, this department of anatomy has been much advanced by the distinguished labours of Fohmann,[‡] Lauth,[§] and Panizza.[||]

The forms in which the absorbents take their rise may be seen, in preparations of these vessels injected with mercury, to be two:—

First, as a network, of which the meshes are sometimes oblong, sometimes more equilateral. The meshes are sometimes smaller even than the diameter of the minute lymphatics which form them; and if, where the network is so very close, the vessels are at the same time very irregular in size, the structure may to the superficial observer have the appearance of aggregated cells, though the parts that look like cells are merely inequalities and slight dilatations of the vessels. In other parts, where the meshes are larger, the reticulated structure is immediately evident. The diameter of the vessels varies very much; but they are never so minute as the capillary blood-vessels, and I am acquainted with no absorbent vessels which are not visible to the naked eye.

The second form in which the absorbents take their rise is that of small cells, more or less regular, and communicating one with another. Such appeared to me to be the structure of the injected lymphatics of the umbilical cord, and of those of the cornea, the nature of which, however, is doubtful. This was also the appearance of the lacteals in the calf, which I injected by forcing mercury into one of the trunks which were issuing from the intestines, filled with chyle, in a retrograde direction, so as to overcome the resistance offered by the valves. I succeeded tolerably well in one case by forcible injection. The great number of cells which are by this means filled with mercury suggests the idea that the absorbents take their rise in the cells of the cellular tissue itself. Fohmann,[¶] indeed, is of opinion that what we call cellular tissue consists merely of lymphatic vessels. This, however, appears to me very doubtful. The identity between the cells that I have described and lymphatics is especially problematical in those parts in which the cells are more particularly met with, and in which none of the long and regular lymphatic vessels occur, as is the case in the umbilical cord and cornea. From having compared good injections of lymphatics with other specimens in which the injection has not succeeded so well, and from some experiments of my own, I am inclined to believe that many of what are called the cellular lymphatic radicles are not really lymphatics, and that the general form in which the radicle lymphatics exist, even where these vessels are most numerous, is that of a close and often regular network.

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[*] Das Weisse Blut. Erlangen. 1832.

[†] A farther account of the chyle is given in the Section on Digestion.

[‡] Das Saugadersystem der Wirbelthiere. i. Heft. Heidelberg, 1827, fol.

[§] Essai sur les Vaisseaux Lymphatiques. Strasb. 1824. Ann. des. Sc. Nat. t. iii.

[||] Osservazioni Antropo-zootomico-fisiologiche. Pavia, 1833.

[¶] Tiedemann's Zeitschrift für physiologie, iv. 2.

Do the lacteals commence by open mouths?—The lacteals of the small intestines arise partly in the villosities; but they also commence in the whole surface of the mucous membrane of the intestinal canal. When the lacteals are injected with mercury, none of the metal escapes from the surface of the mucous membrane. The villi also are not perforated at their extremity, as Lieberkühn, Cruikshank, Hedwig, and Bleuland, incorrectly supposed.*

I have found that if a portion of fresh sheep's intestine, removed with the mesentery, and tied at one extremity, is strongly distended with milk by means of a syringe, the lacteals immediately become filled, and the milk moves very rapidly through them; for if any of the lacteals are emptied by pressing onwards their contents, they are seen to re-fill immediately with milk from the intestine, particularly if the intestine is compressed at the same time. If the passage of the milk into the lacteals in this experiment were effected without any previous laceration of the mucous surface, it would be an important fact. But in every case, however, in which the lacteals become injected by this procedure, there seems to be laceration of the mucous membrane at some point; for the lacteals fill suddenly; and, on examining afterwards the inner surface of the intestine, there is frequently found a spot here and there, where the mucous membrane has lost its integrity. Consequently I attribute no importance to these experiments, in reference to the question of the existence of openings in the extremity of the villi. I observed the phenomenon in no other animal than the sheep.

It still, however, remains an undecided question whether the globules of the chyle enter the lacteals already formed. The varying opacity of the chyle, according to the difference of the food taken, is the chief argument in favour of the globules being derived from the cavity of the intestine, and not afterwards formed in the lacteals. But where are the openings by which they enter these vessels?—for they must require larger pores than those by which all soft tissues, and even the walls of the capillaries, are rendered permeable to water and matters in solution, but which are too minute to allow the escape of the red particles of the blood from the capillaries. All good observers agree that there are no visible openings in the villi of the intestines; and I have myself repeatedly examined the villi of the intestines of the calf, ox, rabbit, hog, and cat, without having even perceived any perforation in their extremity. No opening certainly exists at that part of the villi.

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* See Rudolphi, Anatomisch-physiol. Abhandlungen; and Albrecht Meckel, in Meckel's Archiv. t. v.

Structure of the intestinal villi.—The villi of the intestines are short processes, a quarter of a line to a line, or at most a line and two-thirds in length, rising from the surface of the mucous membrane, and giving this membrane, when magnified, the appearance of a thick fleece. Their form is sometimes cylindrical, sometimes lamellar, and frequently pyramidal.

Rudolphi at first believed that the villi were devoid of blood-vessels, and A. Meckel imagined that all the injection which entered them did so by imbibition or extravasation. Meckel could not have had before him good preparations of injected villi when he came to this conclusion. Not only can the vessels of the villi be beautifully shown by injection, as Doellinger, Seiler, and Lauth have described and represented, but I have, with the naked eye as well as with a lens, seen them filled with blood. Once I observed this in the calf, and afterwards in the dog, the intestine being examined immediately after death before it was washed.

The extremity of the villi presents the same delicate texture as the rest of their surface. The assertion of Bleuland and others, that they had an opening at their extremity, was refuted by Rudolphi, who expressed all that has hitherto been known of the structure of these parts in the following words:—"They have never any visible opening; in their interior there is a network of blood-vessels, which can seldom be demonstrated, however, except by injection; and the lacteals also take their rise by a network within the villi."

It appears to me to be an important circumstance, that the villi are in part hollow, and are formed of an exceedingly delicate membrane in which blood-vessels ramify. The simple cavity I have found principally in the cylindrical villi. By comparison I have ascertained that the thickness of the membrane which forms the villi in the calf is $\frac{1}{330}$th of an inch, and the diameter of the capillary blood-vessels which run in this membrane, may be reckoned at from $\frac{1}{3700}$th to $\frac{1}{1830}$th of an inch. An opportunity occurred, recently, at the dissecting-rooms in Berlin, of examining the villi of intestines in which the lacteals were filled with chyle in the human subject. They were found to contain a simple cavity running from base to apex. This was proved both by the microscopic examination of the villi by Henle, and by their injection with mercury by Schwann, who forced the mercury into the lacteals which were distinctly visible in the mucous coat, and thus filled the villi even to their closed extremity. There is something of a very different nature, which might be mistaken for hollow villi. This is a kind of epithelium, but of extreme delicacy. It is not solid, like an epidermis; on the contrary, although coherent in a membranous form, it is so nearly allied to mucus, that it seems to me to be a secretion intermediate between epithelium and mucus.

Professor Krause* has lately had an opportunity of seeing the lacteals in the villi of the jejunum, beautifully filled with chyle, in the body of a young man who had been hung soon after taking a full meal of farinaceous food. The lacteal that issued from each villosity arose by several smaller branches, of which some terminated by a free extremity, others anastomosed with each other.

In the experiment already mentioned, in which the lacteals are injected by distending the cavity of the intestine with milk, villi filled with the milk may likewise be detected at some points. The experiment must be made very often before this accidental injection of the villi takes place. It is probable that the milk finds its way into the villi, not through the intestinal surface of the villi, but in a retrograde course from the network of lacteals which the milk had previously entered through lacerations of the mucous surface.

I have never perceived any opening at the extremity of the villi, and in my earlier examinations of them I could see no appearance of foramina on any part of their surface. But I have lately observed, in portions of the intestine of the sheep and ox, which had been exposed for some time to the action of water, that over the whole surface of the villi there were scattered very indistinct depressions, which might be regarded as oblique openings. However, I mention this observation with great hesitation and distrust. The villi must be examined with a simple microscope, and must be under water on a black surface. The appearances here spoken of as resembling oblique openings on the surface of the villi are, according to Henle, produced by the nuclei of the epithelium cylinders covering them. (See the account of epithelium in the chapter on Histogeny.)

Structure of the intestinal mucous membrane.—The villosities of the intestines, whether they have or have not open mouths on their surface, cannot possibly be the sole organs for the absorption of the chyle; for in many animals they do not exist. This consideration led me to examine the mucous membrane itself from which the villi are processes, and which is common to all animals.

If in a well washed portion of the small intestine of any mammiferous animal we examine the structure of the membrane by which the villi are connected at their base, by means of a simple microscope, we perceive, without much difficulty, an immense number of very small openings, which are about twice or three times as large as the red particles of the blood of the frog, and eight or ten times as large as the same bodies in Mammalia. These minute openings are in Mammalia sometimes so close and numerous, that the portion of membrane which separates them is scarcely as broad as the openings themselves; generally, however, they are more widely separated; and in this case they give a spongy and exceedingly soft appearance to the membrane. Even the bases of the villi appear in sheep and oxen beset with these foramina. They are the openings of Lieberkühn's follicles.†

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* Müller's Archiv. for 1837. Heft i. p. 5. See also Valèntin, ibid. 1839, p. 178.

† See Boehm, De Gland. Intestinal. Struct. Berol.

The absorbent glands in birds are almost wholly wanting, except in the neck; and in reptiles and fishes they do not exist at all. In these animals they seem to be replaced by mere plexuses of absorbent vessels. The glands themselves, in fact, consist merely of reticulated anastomoses and interlacements of the vessels. The *vasa inferentia* of an absorbent gland divide on entering it into small branches, and by the reunion of small branches are formed the *vasa efferentia*, which are less numerous and somewhat larger than the *vasa inferentia*. In consequence of the free anastomoses of these two sets of vessels, so as to form a network of lymphatics, of which the gland is constituted, we are enabled to fill the *vasa efferentia* with mercury forced into the *vasa inferentia*. The simple absorbent glands resemble mere plexuses of absorbent vessels; but one of the larger glands, when filled with mercury, has a cellular appearance. Even these apparent cells, however, seem to be merely small dilatations of convoluted vessels; the network of absorbents in other parts has also frequently a cellular appearance; the small spaces between the vessels not being distinguished without careful observation. The passage of mercury through the glands when the absorbent vessels going to them are injected is in favour of this opinion. The opposite views of Cruikshank, who admitted the existence of cells in these glands, and of Meckel, Hewson, and Mascagni, who regarded the apparent cells as dilatations of the convoluted absorbent vessels, can be easily reconciled.

Structure of the absorbent vessels.—It is very certain that the coats of the absorbents in the absorbent glands, as well as in other parts, are traversed by capillary vessels; even the lacteals on the intestines, according to Fohmann, possess an internal coat, which extends as far as the network from which they take their rise; and it has been already mentioned that the capillary vessels in the villi are very numerous. Consequently even the absorbents, which form the radicle part of the system are to be regarded as organs of very complicated structure, into which capillary vessels enter as elementary parts. The thoracic duct and the lymphatics have according to Valentin,* three coats; an external cellular, a middle fibrous, and an internal thin coat in which no structure can be distinguished, but which forms valves, by the arrangement of which the flow of the lymph towards the larger trunks of the lymphatic vessels is favoured, and its reflux in the opposite direction impeded. Henle† states that he has found a layer of epithelium also on the inner surface. The fibres forming the middle coat are described by M. Valentin as resembling those of cellular tissue in outline, but as having greater elasticity; they enter into the structure of the valves.

We have now to inquire whether absorbent vessels at their origin, or in any part of their course, have any communication with canals of other kinds, besides that with the venous system, by means of the trunk of the absorbent system,—the thoracic duct.

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* Repertorium, Bd. ii. p. 242.

† Müller's Archiv. 1838, p. 128.

Do the absorbents communicate with the secreting canals of glands?—If any open communication between the lymphatics and secreting canals really exists, which Panizza denies,—and certainly with justice,—it can only be by means of the trunks of the secreting canals; for the smaller lymphatics which form the ultimate network, are many times larger than the blind extremities of the secreting canals of the conglomerate glands. The *connection of lymphatics and arteries,* of which Magendie speaks so summarily, is not better proved.

The *connection of the lymphatics with the small veins,* however, has been again rendered a subject of controversy, in consequence of Fohmann's observations.

Fohmann, Lauth, and Panizza, have discovered communications, visible to the naked eye, between the lymphatics and the veins of the thigh and pelvis in birds. I have also discovered a connection between the lymphatics of the thigh and the ischiadic vein in the frog. But this communication of the larger trunks is very different from a communication of the smaller lymphatic vessels with minute veins, which Fohmann asserts to exist in birds, reptiles, and fishes, and of which he has given representations. He admits, however, that in man and Mammalia, which have lymphatic glands, this communication of the absorbents with the veins does not exist, except in the glands. The statements of Lippi[*] concerning the communications of the lymphatics and veins, and his representations of them, have been shown by Fohmann (l. c. p. 4) and Panizza to be undeserving of much confidence. Fohmann, however, maintains that the veins and absorbents do communicate in the lymphatic glands, as had been observed by J. F. Meckel, the elder, and Ph. F. Meckel, when injecting the absorbent vessels with mercury. I doubt very much the existence of an open actual communication between the lymphatics and minute veins in the glands; and the circumstances which induce me to doubt it are, that, when glands are injected from their excretory duct, the small veins of the gland also frequently become filled with the mercury, and that the cases in which this occurred to me were always those in which the ducts had not been well filled,—their acini not distended; and, lastly, that similar extravasation takes place from the ducts of the mammary gland into the lymphatics of the gland, and this likewise in cases where the acini of the mammary gland are not well injected. The coagulated lymph in the absorbent glands resists the passage of the mercury; the substance of the gland is lacerated; and the coats of the lymphatics being supplied with capillaries which are continuous with veins, the rupture of one lymphatic in the interior of a gland must be attended with laceration of the reticulated capillary vessels and veins.

In the same manner, also, as E. H. Weber observes, fluids find their way very easily from the branches of the pulmonary artery into the bronchi, although no natural communication exists between them. I regard in the same light the passage of injection from one order of vessels into another in the secreting glands, namely,—from blood-vessels into the secreting canals, and from the secreting canals into blood-vessels.* If I should ever see a direct communication of a lymphatic external to the glands with a small vein, I would acknowledge it as a thing evident to the senses, without, however, admitting the existence of such communication in the interior of a gland, where it is invisible.

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[*] Illustrazioni fisiologiche e pathologiche del sistema linfatico-chillifero, etc. Firenze, 1825.

Terminations of the absorbents.—Since the communication of lymphatics with small veins has not been observed in man and Mammalia, the absorbent and venous systems can be regarded as connected only by the principal lymphatic trunk, the thoracic duct, which opens into the left subclavian vein, and by smaller lymphatic trunks which pour their contents into the internal jugular and subclavian veins of the right side. All other communications between the absorbents and the great veins, seem to be exceptions merely to the normal structure; such was the case witnessed by Professor Wutzer and myself, in which a branch was given off from the thoracic duct and immediately entered the vena azygos.† This branch is worthy of notice, however; for Panizza has found that in the hog a regular communication exists between branches of the thoracic duct and the vena azygos.‡

b. Of the lymph-hearts of Reptiles and Amphibia.

The lymph-hearts of the Amphibia were discovered in the year 1832.§ They are muscular sacs which pump the lymph into the trunks of the venous system, at the anterior and posterior parts of the body. There are usually four, two anterior and two posterior; in the frog the posterior lymph-heart on each side is situated in the ischiadic region just beneath the skin; the anterior lies deeper, namely, just over the transverse process of the third vertebra. The pulsations of these sacs are quite independent of those of the heart, and continue when the heart is removed from the animal, even after the body of the animal is cut in pieces; the pulsations of the cervical pair are not always synchronous with those of the pair in the ischiadic region, and even the corresponding sacs of opposite sides are not always synchronous in their action. They contract about sixty times in a minute. They contain colourless lymph; and the lymphatic vessels, and lymph spaces of the extremities, can be inflated from them. Similar pulsating organs seem to exist in all reptiles. I have hitherto discovered the superior pair in no other animals than the frogs and toads. The inferior pair I have found in the salamanders and lizards; in these animals they are situated at the sides of the root of the tail behind the ilium, and are more difficult to find than in the frog, where they lie immediately under the skin. Panizza* has discovered the inferior pair of these lymphatic hearts also in serpents.†

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* On the question of the communication of the lymphatics and veins, see E. H. Weber's observations in Hildebrandt's Anat. t. iii. pp. 113–121.

† See Wutzer in Müller's Archiv. 1834.

‡ Compare Otto, Patholog. Anat. p. 366. Otto met with an instance in which there were two thoracic ducts; one passing to the right side, the other to the left, as is usually the case in birds.

§ See Müller, in Poggendorf's Annal. 1832; and the Philos. Transact. 1833, pt. 1.

CHAPTER III.

OF THE FUNCTIONS OF THE ABSORBENTS.

During the circulation of the blood through the minute capillary vessels, the red particles exert a vivifying influence on the parenchyma, and at the same time undergo a change of colour; but they can be traced in their course into the veins,—they are not retained in the tissue. The fluid portion of the blood, however, with the fibrin and albumen in solution, like every fluid matter, is capable of permeating the walls of the capillaries, and of being imbibed by the particles of the tissue contained in the meshes of the capillary network through which the blood is flowing. The dissolved ingredients of the blood thus imbibed by the parenchyma must serve the purposes of nutrition and secretion. Hence it is that venous blood contains less fibrin than arterial blood. After the purpose of nutrition is fulfilled, the fluid portion of the blood imbibed by the tissues will, by the same process of imbibition, collect in the network of lymphatics, which occupy in all parts of the body the interstices of the proper tissues of the organs; a direct communication between the capillaries and lymphatics by means of vasa serosa is therefore not needed for the passage of the fluid parts of the blood into the lymphatics, and indeed no such communication has been proved to exist.

The fluid part of the blood having supplied the materials for the nutrition of the tissues, is therefore again returned to the circulation by the lymphatic vessels. The lymph consequently must, in its composition, be exactly identical with the fluid portion of the blood, or liquor sanguinis, and the blood itself must consist merely of lymph and red particles. An observation which I have made, and which can be easily repeated, is sufficient to prove that the fluid contained in the lymphatic vessels is formed principally of the fluid parts of the blood, and is not a perfectly new fluid. I have observed that when the blood of the frog does not coagulate, the lymph also does not coagulate. Thus, when frogs have been kept out of water for eight or more days during the summer, their blood often loses its property of coagulation; and under such circumstances the lymph taken from the lymph cavities of the same animal, affords no coagulum. So that the peculiar state of the fibrin, or its absence in the blood of the frog at certain times, determines the very same state of the fibrin in the lymph, or its absence from that fluid.

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* Müller's Archiv. 1834, p. 300.

† For a more particular account of their structure and action, see E. Weber in Müller's Archiv. 1835, p. 535; and Valentin, Repertorium, Bd. i. p. 294.

1. *Of the absorption by the lymphatics and lacteals.*

Proofs that they absorb.—It might at first appear doubtful whether the lymphatics and lacteals do really absorb, were it not that the lymph contains peculiar particles or globules, that absorption by the lacteals is a well-ascertained fact, and that the colour of the chyle varies, becoming whiter or more opaline, according to the food taken. There are circumstances, however, which prove the fact of absorption by lymphatics in other parts. It is not merely that the lymphatics often become painful, that red streaks appear in their course, and that the neighbouring lymphatic glands become swollen after the application, by friction, of irritating matters to the skin; the lymphatics around collections of peculiar animal fluids have been seen filled with these fluids. I attribute no importance to the somewhat extravagant assertions of Mascagni, who states, that in animals which died from pulmonary or abdominal hemorrhage, the lymphatics of the pleura and peritoneum have been seen filled with blood. But Assalini, Saunders, Mascagni, and Soemmering have all observed bile in the lymphatics coming from the liver, in cases where the bile ducts were obstructed.* Tiedemann and Gmelin also, after tying the *ductus choledochus* in dogs, found the lymphatics of the liver filled with a fluid of a deep yellow colour; the lymphatic glands which these lymphatics passed through were yellow, and the yellow fluid taken from the thoracic duct contained the components of the bile.† Lymphatics around osseous tumours have been found to contain calcareous matter.‡ Mr. Hunter§ found in the spermaceti whale a plexus of vessels, apparently lymphatics, about the nose or anterior part of the nostril, filled with spermaceti and oil.

Magendie was the first to deny the absorbing power of the lymphatics. Hunter had asserted that coloured water injected into the abdomen of an animal, is soon discoverable in the lymphatics. Flandrin has made the experiment in horses without success; and Magendie assures us that, with M. Dupuytren, he repeated similar experiments more than one hundred and fifty times, and never found any of the substances absorbed in the lymphatics. On the other hand, Meyer and Schroeder van der Kolk observed an evident, though slow, absorption of foreign matters from the intestinal canal by the lymphatics.

Drs. Lawrence and Coates, of Philadelphia, witnessed the absorption of prussiate of potash; but, according to their observations, colouring matters were not absorbed. Hallé and others, after the introduction of colouring matters into the stomach, could not detect them in the thoracic duct, while they had evidently entered the blood and the circulation.‖

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* See Weber in Hildebrandt's Anat. iii. p. 123.

† Die Verdauung nach Versuchen, ii. 40.

‡ Otto, Patholog. Anat. i. 372.

§ On the Structure of Whales. Works, vol. iv. p. 347.

‖ See also Tiedemann and Gmelin, Versuche über die Wege, &c.

The result of most experiments is, that salts are the only foreign matters absorbed by the lymphatics. Thus the numerous experiments of Tiedemann and Gmelin, cited at page 248, show that colouring matters introduced into the intestinal canal, are not taken up by the lacteals, although they are afterwards found in the blood and urine. Salts were the only foreign substances that they could detect in the chyle, and these but a few times.

Peculiarities of the lymphatic and lacteal absorption.—The conclusion which must be drawn from a consideration of all the facts is, that the lymphatics do really absorb, but that their absorbing action is confined to particular fluids, for which perhaps they have an affinity: they have but little tendency to take up foreign matters, of which a few only, such as salts, are absorbed by them, while others, such as colouring matters, as a general rule, do not enter them at all. The matter which the lymphatics are ordinarily engaged in absorbing, is the *liquor sanguinis,* which, during the circulation of the blood through the capillaries, is imbibed by the tissues. Besides this fluid, however, small molecules are taken up from the parenchyma of the organs and form the globules of the lymph, in the same manner as the globules of the chyle are, as it appears, absorbed by the lacteals with the fluid portion of the chyle from the food contained in the alimentary canal.

The organic process by which the lymphatics absorb is therefore materially different from that by virtue of which the capillaries imbibe all foreign matters in a state of solution; it is also different from the process of absorption in the radicle fibres of plants, by which every matter which is in solution is absorbed.*

Power by which the lymphatics and lacteals absorb.—I confess that the act of absorption in other parts as well as in the intestines, is to me quite an enigma. Capillary attraction, by which some persons would explain so many processes in the animal body, accounts for the filling of capillary tubes only when they are empty, or when they have the power of emptying themselves from time to time; it does not explain the absorption and motion of the organic fluids. It is probable that some other kind of attraction, and this certainly not of a merely physical nature like capillary attraction, but an organic attraction of a kind hitherto unknown, is here in action. I have never seen the slightest motion in the villi of the intestines, although I have laid open the intestine in a living rabbit and examined its internal surface under warm water. Nor have I observed any sign of movement even in the lacteals of the mesentery, in the *receptaculum chyli,* or in the thoracic duct. I have applied the wires of a strong galvanic battery to the thoracic duct of a goat, which was opened as quickly as possible, while still alive, but could perceive no contraction: it was not till some time had elapsed, that the duct appeared to have become somewhat narrower at the point to which the wires had been applied, and presented several very inconsiderable constrictions.

In no point, perhaps, do plants and animals so much resemble each other as in the ascent of fluids from absorbing surfaces in the absorbent vessels of animals and the ascent of the sap in the vessels of plants. The ascent of the sap in plants is, however, effected solely by the action of the roots and their spongiola, as proved by the experiments of Dutrochet. The structure of these plants is cellular, and from it the imbibed and absorbed fluid finds its way into the sap vessels proper. The villi of the intestines are not essential organs for the absorption of the chyle. For not only is absorption performed by the lymphatics without villi in all parts except the intestines, but the intestines of many animals are destitute of villi. Nevertheless, the villi of the intestines are in some measure analogous to the spongiola of the roots of plants; it must, however, be remembered that the absorbents in the villi have the same structure as in other parts which have no villi.

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* Tiedemann's Physiol. i. 223. English Translation, p. 85.

Dutrochet explained the phenomena of absorption both in plants and animals by the laws of endosmose. It is easy, however, to perceive that the phenomena of endosmose in dead animal membranes are by no means sufficient to account for the organic process of absorption in the animal and vegetable kingdoms.

It is probable that there is no mechanical apparatus for absorption in the radicles of the absorbent system, since in plants no such apparatus exists. Absorption seems to depend on an attraction, the nature of which is at present unknown, but of which the very counterpart, as it were, takes place in secretion; the fluids altered by the secreting action being impelled towards the free side only of the secreting membranes, and then pressed onwards by the successive portions of fluid secreted. In many organs,—for instance, in those invested with mucous membranes,—absorption by the lymphatics and secretion by secreting organs are going on at the same time on the same surface.

Since the action of the absorbents depends on an organic property, circumstances which affect the organisation of a part will necessarily elevate or depress their action. Thus in inflammation, as Autenrieth remarked, (*Physiologie*, ii. 224,) the action of the absorbents appears to be diminished, and hence the frequent occurrence of an enduring œdematous swelling around an inflamed part.

It is still uncertain how the remedial means, which are supposed to excite absorption, produce their effects; the cases in which their action is evident are few. There are substances called resolvents, which are capable of softening and dissolving the matters collected in superabundant quantity in the interstices of the elementary parts of tissues. The possibility of such a process taking place is shown apparently by the organic fluids themselves, in which one ingredient is frequently the menstruum for another; thus, for example, animal matters are kept in a state of complete solution by their organic union with mineral substances, as is the case in the serum, or with other organic substances, as in the bile, in which picromel is the solvent menstruum of the cholesterine. The use of resolvents in medicine is, however, very limited, because many substances, which out of the body have the power of dissolving animal matter, have a destructive action on living animal textures. The assertion, that the lymphatics continue to absorb after death, appears to me to be wholly without foundation. (See *E. H. Weber, loc. cit.* vol. iii. p. 101.)

2. *Change effected by the lymphatic and lacteal vessels on their contents.*

The absorbent vessels, the parietes of which are supplied with capillaries, seem to effect a change in the composition of the chyle and lymph. The absorbent glands have the same action; they serve merely as means of increasing the surface of action; for, in the lower vertebrata, they are replaced by mere plexuses, and are, in fact, merely plexuses in a more highly developed form. The chyle in the lacteals of the mesentery, according to Tiedemann and Gmelin, is not coagulable until it has passed through the mesenteric glands. The lacteals and their glands appear, therefore, to have the power of converting, by the agency of their parietes, a part of the albumen of the chyle into fibrin. In many diseases this action of the lacteals on the elementary combination of their contents is modified, or the vessels themselves suffer from the action of fluids morbidly formed, as in scrofula.

It is probable, as E. H. Weber has endeavoured to prove, that the absorbents produce a change in the composition even of foreign matters which they take up. Thus Emmert has observed that after the abdominal aorta had been tied, the poison of the *angustura virosa* inserted into a wound of the foot, did not exert its deadly effect, and that prussic acid applied in the same way had also no effect on the animal, when the circulation in the lower extremities was stopped by ligature of the abdominal aorta. Now these poisons by mere imbibition could enter the lymphatics as well as the blood-vessels, so that the absence of their usual effects in these cases must be attributed to a change effected by the lymphatics in the matters which they absorb.

The absorbents are endowed with a peculiar sensibility to the action of foreign matters, becoming painful, sometimes inflamed and swollen, so as to be distinguished through the skin by red streaks when such matters have been absorbed. Under the same circumstances, the glands in the neighbourhood of the absorbing spot also swell and become painful. Ordinarily, if the absorption of the irritating matter is not continued, the swelling disappears, but sometimes the glands inflame and suppurate. This enlargement of the neighbouring glands is observed to take place under various circumstances, such as the introduction of an animal poison under the epidermis, the application of a blister, the bite of a snake, a cut or prick received in opening a putrescent body, or the inunction of tartar emetic ointment or mercury; it often occurs, also, in glands near an inflamed part in which pus is forming. Thus, the inguinal glands swell in cases of gonorrhœa, or of venereal infection of the genitals where there is no gonorrhœa. The mesenteric glands seem to stand in the same relation to the intestines, as the superficial glands to the skin; they become inflamed when the intestines are inflamed and ulcerated, —for example, in typhus abdominalis.

3. *The motion of the lymph and chyle.*

The powers by which the lymph and chyle are moved are unknown. It is possible that the absorbent vessels and thoracic duct propel their contents by imperceptible progressive contractions; but it is not known whether this is the case. Tiedemann and Gmelin, however, observed that the thoracic duct, when punctured, expelled its contents in a jet. They suppose, therefore, that the lymphatics and lacteals, although not endued with rhythmic contractility, nevertheless have the power of propelling onwards their contents. If they really exert such a power, it must be facilitated by their valves; the arrangement of which, indeed, is such that even external pressure applied to the lymphatics or lacteals by the muscles, must have the effect of propelling onwards the lymph and chyle.

The motion of the lymph and chyle most probably depends principally on the continued absorption going on in the radicle network of the lymphatics, in the same way as the ascent of the sap in plants, during the spring, depends solely on the constant absorbing action of the roots.

The lymph-hearts which I have discovered in reptiles and Amphibia, must considerably facilitate the motion of the lymph in those animals. They discharge the lymph of the lower part of the body directly into the ischiadic vein, that of the upper part of the body into a branch of the jugular vein. In Mammalia and man it is only in the subclavian veins that the chyle and lymph are mixed with the blood; all the chyle and the greater part of the lymph being poured into the left subclavian vein by the thoracic duct. The lymph and chyle are often still to be detected in the blood of the superior cava. The process of their conversion into blood in their course through the circulation has been already described. I have never been able to perceive the slightest motion in the thoracic duct and *receptaculum chyli*, or in any part of the absorbent system of Mammalia (p. 278); and in reptiles the lymphatic hearts are only the parts of the absorbent system in which I have perceived any contractions.

The rate of the motion of the lymph in the lymphatics is quite unknown.—Some idea of the rate at which the chyle moves, may be formed by observing the time required for the distended lacteals in the mesentery of an animal just opened to become invisible, and by ascertaining the quantity of the fluid which can be collected from the thoracic duct. In Magendie's experiment half an ounce of chyle was collected, in five minutes, from the thoracic duct of a middle-sized dog. Collard de Martigny obtained nine grains of lymph, in ten minutes, from the thoracic duct of a rabbit which had taken no food for twenty-four hours. He found, after having pressed out the lymph from the principal lymphatic trunk of the neck in a dog, that the vessel filled again in seven minutes; in a second experiment, it filled in eight minutes.*

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* Journ. de Physiol. t. viii.

BOOK III.

OF THE CHEMICAL CHANGES PRODUCED IN THE ORGANIC FLUIDS AND ORGANISED TEXTURES UNDER THE INFLUENCE OF THE VITAL LAWS.

THE power by which elementary substances are, in the organic system, united into ternary and quarternary compounds, in opposition to their ordinary chemical affinities, which would lead them to form binary compounds, is without doubt a peculiar "force" or "imponderable matter" unknown in inorganic nature;—probably the same force or principle that governs the formation and nutrition of the different organs of the body after a plan of strict adaptation. (See page 29, *et seq.*) To attribute to electricity the production of all organic compounds would be a perfectly gratuitous hypothesis. Until the properties of the principle which influences organic combinations are known, it can be spoken of merely as a power, the existence of which is certain, but of which the nature cannot be defined, and it is in this sense that we use the terms "vital principle" and "organising force." The law which regulates the action of parts endowed with this power on other substances, is that of assimilation.

The material changes which occur in the organic system, may be divided into the purely chemical and the organic chemical.

1. Purely chemical changes ensue in the animal system when the vital principle loses its influence on the textures of the body, or becomes incapable of counterbalancing the tendency of the elements to form binary compounds in accordance with their ordinary chemical affinities.

Concentrated acids and alkalies unite with the component elements of living animal bodies, and produce new substances, the animal matter being destroyed. Dilute muriatic and acetic acids in the gastric juice aid in the solution of elementary substances. The greater number of metallic salts combine with animal matters readily, and in definite proportions. (See *Mitscherlich* in Müller's Archiv. 1836, 1837.)

These purely chemical actions are of frequent application in therapeutics. The property which albumen possesses of precipitating corrosive sublimate, and uniting with it to form an insoluble substance, suggested to Orfila the happy idea of trying it as an antidote. (Huenefeld, *Physiol. Chemie*, i. pp. 65, 89.) An antidote, as Huenefeld remarks, must have a strong affinity for the poison, and but slight chemical affinity for the animal body, so that it may be introduced into the system without ill effects. Sulphur neutralises arsenic;

and, by giving rise to an insoluble compound, renders it less hurtful. It is on account of their insolubility that preparations of mercury which contain sulphur are inert in the treatment of syphilis. (Huenefeld, *Physiol. Chemie*, p. 66.) The soluble sulphates are antidotes for poisoning by barytes and salts of lead, because the sulphates of barytes and of lead which are formed are insoluble. (Ibid. p. 67.) Magnesia neutralises the acid of the stomach. The success attending the administration of the carbonates of alkalies in cases of lithic acid deposit, and of the formation of calculus, from the urine, depends on the lithic acid being dissolved by the alkalies, and the urine rendered alkaline. Salts of vegetable acids are useful in the same way, being converted into carbonates in the animal body or yielded in that form to the urine. Nitric acid, chlorine, and chlorates have been used with success, in preventing the development of sulphuretted hydrogen, ammonia, and hydrosulphate of ammonia, from sores of hospital gangrene and from cancerous sores. The use of mineral acids in putrid fever with a tendency to alkalinity of the fluids, may be regarded in the same light.

The colouring matter of madder evinces a strong affinity for phosphate of lime even in the living body, the bones being the only parts which are coloured by it when it is taken with the food. Lastly, many foreign substances taken up into the circulation, are in part chemically changed, and are again expelled from the system in their changed or unchanged state.

2. In other cases, certain substances, particularly those generated by the decomposition of the organic matter in diseased animals, act on other living animals in a manner which resembles the chemical process of fermentation.* Thus, contagions give rise to the production of similar changes of composition in the animal matters of other living beings.

3. Chemical compounds and simple elementary substances, however, by affording the components which were deficient for the formation of new organic compounds in the body, may favour the production of these compounds instead of decomposing them, and thus assist the operations of the vital principle. Thus the admixture of a certain proportion of mineral substances in the food is necessary. The change effected in the blood during respiration is an organic chemical change, in which a binary compound is formed and separated from the blood.

4. Organic substances again may reciprocally decompose each other even without the influence of the vital principle. Thus saliva, according to Leuchs, (*Poggendorf's Annal.* 1831, p. 5,) and Schwann, (*Müller's Archiv.* 1836, p. 138,) converts boiled starch into sugar, and Tiedemann and Gmelin have shown that starch is changed in the stomach of animals into gum of starch and sugar.

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* According to recent observations, the process of fermentation depends on the growth of a very simple vegetable (the Torula Cerevisæ of Turpin) which exists in yeast in the form of the yeast globules; and, nourishnig itself by extracting some elements from the organic matter of fermenting fluids, causes the alcohol, or acetic acid, to be set free.

Fibrin or muscle is said like yeast, to excite fermentation in solution of sugar. Dr. J. Davy, however, on performing the experiment with beef, and continuing it three or four days, obtained gum in place of alcohol. (*Kastner's Archiv.* 1831, p. 396.) The organic digestive principle, or "pepsin," secreted by the walls of the stomach, dissolves coagulated albumen and fibrin very readily, even out of the body, and so modifies their composition that they acquire different chemical properties. In the animal system, however, the action of organic fluids on one another is modified by the vital principle. The action of saliva and of bile in the process of digestion, is not intelligible from the effects which they produce on organic compounds out of the body. The processes just alluded to, and, perhaps, those mentioned in the following paragraph, also, appear to belong to that class of chemical actions to which Berzelius (*Fortschritte d. physisch. Wissensch. Bd.* 15. pp. 237–247,) has given the name "catalytic." They are actions in which a certain matter by its presence gives rise to decompositions or combinations in other substances, without itself undergoing any appreciable change. Thus, the presence of sulphuric acid decomposes alcohol into ether and water; finely divided platina and other metals cause hydrogen and oxygen to unite suddenly. Dilute sulphuric acid acting upon starch, converts it into sugar, and an organic substance called "diastase," found in abundance in the buds of the potato, effects the same change in the starch of that tuber; a change necessary for the nutrition of the plant. Thousands of such catalytic actions, Berzelius remarks, are, probably, going on in the economy of organised bodies. It has been recently stated by M. Fremy, (*Comptes Rendus*, 1839, Juin 17 and Juillet 30,) that many animal membranes, but particularly that of the calf's stomach, have the property of converting sugar of milk and other saccharine substances into lactic acid, and organic salts, such as the citrates, malates, and tartrates of potash and soda, into carbonates, when solutions of these substances are brought into contact with them out of the body; and that the membranes themselves seem to undergo no change since the same portions of them serve for repeated experiments. All these facts strengthen the probability of the view, that the changes of composition constantly going on in organic bodies, do not essentially differ from the ordinary chemical changes. The production of the different secretions even may depend on peculiar "catalytic" actions of the walls of the secreting canals.

5. Organic assimilation is evinced in the changes of composition which organic fluids undergo, while exposed to the influence of living surfaces endued with the vital principle. Thus, the composition of the chyle absorbed from the alimentary canal undergoes a change in the lacteal system; the quantity of fibrin that it contains being greater in proportion to the number of mesenteric glands through which it has passed. In the formation of the different secretions the same action of the tissues on the fluids takes place, but in a modified form, inasmuch as the components of the blood, which have been changed by the action of the tissues, are in this case separated from it.

6. Lastly, assimilation is still more remarkably manifested in the conversion of the organic fluids into the formative particles of the organs in the process of nutrition. The blood in the capillaries comes in contact with the smaller particles of nerves, muscles, mucous membrane, glands, &c., and each tissue exerts its assimilating action on the substances contained in the blood, changing their elementary composition, nourishing itself by their appropriation, and at the same time imparting to them the property of organizing other matters in their turn. The essential phenomenon of this kind of assimilation is seen in the germinal disk (blastoderma) of the egg, before vessels and the blood are formed. The germinal disk increases at the edges so as to form the germinal membrane at the expense of the yolk. The albumen of the yolk gradually undergoes a change of composition, and at last ceases to be coagulable by heat. As soon as vessels are developed, growth is effected by the enlargement of the particles between the capillaries, and by the formation of new vessels. If in an organised texture, or living substance, A, B, C, and D are the elements which are combined in certain proportions to form each organic molecule, the organising principle of the part effects not only the combination of A, B, C, and D to form component particles, but also the union of these particles to form organic tissues; and the organic fluids in contact with them are compelled to change their composition to the combination of A, B, C, and D, that is, to form atoms of this composition, while these atoms are made to unite with the assimilating organ. By atoms are here intended not organic globules, but those invisible atoms which, in chemistry, are supposed to constitute the ultimate particles of a compound.

The production of vital phenomena—of muscular contraction, &c. —is constantly giving rise to the decomposition of a certain quantity of organic material, to replace which new matter is supplied by the nutriment. In this respect, however inapt the comparison may be in other points, the animal machine resembles every other machine, the action of which necessitates the destruction of some material, and which, like the steam-engine, requires a certain quantity of new matter for the continuance of its action. The most wonderful part of the process is, that, while the system gets rid of its old material and developes vitality in the new, it does not lose any vital power with the matter which it casts off; it would therefore, almost appear, either that the vital principle leaves the decomposed elements, and unites itself to the new matter, or that the nutriment itself is a source of increase of the vital principal, supposing that a portion of this principle becomes inert with the destruction of the old components of the animal body. (*See page* 44.)

The first general law that regulates the formation of different animal substances seems, as Autenrieth remarks, to be the law of attraction of similar parts for each other. But the particles of living structures have a great attraction among themselves, and therefore do not leave their combination to unite with the particles of the nutrient fluid, while they attract to themselves the analogous particles from the blood; so that in the exertion of this affinity it seems to be the blood which principally undergoes a separation of its elements. I cannot conclude these remarks better than in the words of Autenrieth:—"Bone secretes only osseous matter; muscle secretes fibrin, and even a morbid scirrhus or a steatoma grows by the deposition of analogous matter. The growth, by the attraction of similar particles, is not manifested merely in the chemical components of an organ; even in its organisation a similar law prevails. A polypous excrescence of the vagina or nostrils differs less in chemical composition than in its organisation from the surrounding healthy parts. Once formed, however, it continues to a certain extent to grow with its own peculiar structure. A cicatrix, although it possesses a structure different from the original organisation of the skin, continues to be nourished in the same form; it even enlarges as the rest of the body grows." (*Autenrieth, Physiol.* ii. p. 181.)

SECTION I.

OF RESPIRATION.

CHAPTER I.

Of Respiration in general.

Composition of the atmosphere.—Oxygen is the essential respirable component of the atmosphere, of which it constitutes twenty-one parts in 100, seventy-nine parts being nitrogen. The proportion of carbonic acid in the atmosphere is extremely small; 10,000 volumes of atmospheric air contain, according to M. de Saussure, only 4.15 of carbonic acid. In the open country the maximum proportion of this gas was 5.74, the minimum 3.15, in 10,000 parts. In the town of Geneva the air contained 0.31 more carbonic acid than in the country. (*Berzelius, Jahrb. übersetzt.* v. *Woehler*, xi. 64.) There are also local impurities, such as an organic matter, which rain water likewise contains, and which, with the concurrent action of light, reddens a solution of silver. (*Gmelin's Chemie*, i. 442.) Air, in which men or animals are breathing, loses a certain proportion of its oxygen, and in its place acquires nearly the same volume of carbonic acid. The same change is effected by respiration in pure oxygen. Although we do not regard respiration really as a species of combustion, yet the great similarity of the changes produced in the air by the two processes cannot but be remarked. In respiration, as in combustion, the nitrogen seems to act quite a neutral part, merely moderating the process by diluting the oxygen.

Respirable and irrespirable gases.—In considering the various gases in reference to respiration and the respiratory organs, a distinction must be made between those that are merely incapable of supporting the process, and such as are actually poisonous in their action. Nitrogen and hydrogen are instances of the former kind;

they do not support life when respired in their pure state, but when mixed with the necessary quantity of oxygen they are perfectly innoxious. Those gases which from their affinity for animal matters are decidedly noxious to the system, must be again divided into two classes; for several gases can be taken into the lungs although poisonous in their action, while others cannot be inspired in any considerable quantity, on account of their exciting spasm of the respiratory organs, particularly of the glottis.

The gases may be classed according to their physiological effects as follows:—

I. *Those gases which support the chemical process of respiration.*

a. Permanently without injury to life.—Atmospheric air.

b. For a certain period, but not permanently.—Oxygen and nitrous oxide. The respiration of oxygen is said to cause even the blood in the veins to become of a bright red colour. But at length its effects are injurious. Allen and Pepys, however, experienced no ill effects from respiring pure oxygen; and a pigeon which they placed in oxygen gas merely became restless and embarrassed, but recovered when restored to the air. Lavoisier and Seguin perceived no disturbance of the functions in Guinea pigs which were kept twenty-four hours in oxygen gas. Allen and Pepys found that when oxygen was inhaled, a larger proportion of carbonic acid was contained in the gas expired than under ordinary circumstances; but in the case of a pigeon, less carbonic acid seemed to be formed than during respiration in atmospheric air. The respiration of pure oxygen is injurious to phthisical patients. Nitrous oxide gas supports life for a short time, but soon has a stupifying and intoxicating effect, producing excitement, illusions of the senses, confusion of mind, and, at length, syncope. (*Sir H. Davy, Researches on Nitrous Oxide.*) A portion of the gas is absorbed into the blood, which becomes of a purple colour, while the face and lips have the colour of death. Nitrogen and a scarcely perceptible quantity of carbonic acid are expired with the gas from the lungs.

II. *Gases which are respirable, but do not support the chemical process of respiration.*

a. Gases which have a positively injurious influence, but fail to support life, simply from containing no oxygen.—Nitrogen and hydrogen. Lavoisier and Seguin caused Guinea pigs to respire a mixture of equal proportions of oxygen and hydrogen; no particular symptoms were produced, and the experimenters found that the same quantity of oxygen was consumed as when the mixture consisted of equal quantities of oxygen and nitrogen, and that no hydrogen was absorbed. The researches of Allen and Pepys seem to show that when hydrogen alone is respired, nitrogen is exhaled from the blood. Allen and Pepys and Wetterstedt[*] state that the respiration of hydrogen produces a tendency to sleep. I placed some frogs in impure hydrogen, as prepared from zinc and dilute sulphuric acid, and they became insensible in a few hours; but when I had previously purified the hydrogen and freed it from the fœtid oil, by passing it through alcohol, a frog lived in it twelve hours, breathing from time to time; at the end of twenty-two hours it was apparently dead, but still moved slightly when taken out and pinched. In other experiments frogs lived only three or four hours, even in pure hydrogen.

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[*] Berzelius, Thierchemie, 101. Traité de Chemie, traduit par Esslinger, t. vii. p. 106.

b. Poisonous gases.—Carburetted hydrogen, phosphoretted hydrogen, sulphuretted hydrogen, arseniuretted hydrogen, carbonic oxide, cyanogen (?). According to Thenard, atmospheric air which contains $\frac{1}{1500}$th of its volume of sulphuretted hydrogen will destroy a bird; when it contains $\frac{1}{800}$th of its volume, it is poisonous to a dog; and with $\frac{1}{250}$th, to a horse. Carbonic acid, also, is one of these poisonous gases. It excites no coughing, even when inspired in large quantity, but produces narcotism and fatal stupor. Atmospheric air, which contains more than 10 per cent. of carbonic acid, is quickly destructive of life. The above gases also destroy life when injected in small quantities into the blood. (*Nysten.* See page 152.)

III. *Gases which in large quantity cannot be inspired, on account of their producing spasmodic contraction of the glottis, and which, when inspired in small quantities, excite coughing.*—All acid gases (with the exception of carbonic acid gas), chlorine, nitric oxide, fluoboric acid gas, fluosilicic acid gas, and ammonia. (*Berzelius, Thierchemie,* p. 103.—*Gmelin, Chemie,* Bd. iv. p. 1527.)

Any fluid,—water, for instance,—acts on the glottis like a solid body, exciting it to spasmodic contraction, so as even to produce suffocation; while very little irritation is produced by the presence of fluid in the lungs themselves, so that a considerable quantity of fluid may be injected into them by an opening in the trachea without exciting cough.

Aquatic respiration.—A part of the animals which inhabit the water,—namely, Amphibia and aquatic Mammalia,—come to the surface to respire atmospheric air, and breathe by means of lungs; others, as fishes, have gills, in which the blood is aerated by the water itself, or rather by the air which the water contains. The water of lakes, rivers, and the ocean, is impregnated with atmospheric air, or, more correctly, with oxygen and nitrogen, in determinate proportions, which it absorbs from the atmosphere. Humboldt and Provençal obtained from 10,000 parts of Seine water, by boiling, from 264 to 287 parts of gas, of which from $\frac{306}{1000}$ to $\frac{314}{1000}$ was oxygen, and from $\frac{8}{100}$ to $\frac{11}{100}$ carbonic acid. It must not be imagined that the water itself undergoes any change during respiration; it is only the gas with which it is impregnated that is changed, the oxygen being removed, and the carbonic acid increased in quantity. When fishes are made to respire water impregnated with oxygen and hydrogen, the oxygen is absorbed, but the quantity of the hydrogen remains unchanged. If fishes are placed in water which has been subjected to long-continued boiling, they die from want of oxygen in the space of four hours, during which time their respiratory movements are continued. Priestley found by experiment that fishes will live ten or fifteen minutes in water which has been freed from air and afterwards impregnated with nitric oxide; but that as soon as the smallest quantity of atmospheric air gains access to such water, the fishes are seized with convulsive motions and die.

The respiratory movements.—The chemical process of respiration is not essentially dependent on the respiratory movements. They merely serve to expel the air or water which has undergone the change induced by the chemical process constantly carried on between it and the blood, and to renew the supply of fresh air or water.

The lungs, by their internal surface, offer an immense expansion for the action of the blood and air on each other; and, as they are never completely emptied by the act of expiration, this action is constant. By the contraction and dilatation of the chest, the motions of which the lungs follow, a portion of the altered contents of the pulmonary reservoir is first expelled, and then a new supply introduced, to undergo change in its turn. Fishes take in fresh water by the mouth, and then, passing it through the branchiæ, expel a portion through the branchial openings, the opercula or gill-covers being alternately raised and depressed.

Volume of air respired.—Sir Humphry Davy calculates that the human lungs, after the strongest expiration, still contain thirty-five cubic inches of air, and after an ordinary expiration, 108 cubic inches; he regards from ten to thirteen cubic inches as the quantity usually expelled at each expiration.* Herbst (*Meckel's Archiv.* 1828,) found that adults of large stature, when breathing tranquilly, inspire and expire from twenty to twenty-five cubic inches; persons of smaller stature sixteen or eighteen cubic inches.

Necessity of respiration.—The length of time during which life can be supported without respiration being performed, varies very much in different animals, being shorter in the Vertebrata, and more especially in the warm-blooded Vertebrata, than in other animals. Warm-blooded animals, placed in the vacuum of the air-pump, die in less than a minute; birds, even in from thirty to forty seconds. Reptiles will live a considerable time in a vacuum, and in irrespirable gases; and in Carradori's (*Ann. de Chim. et de Phys.* v. p. 94,) experiments a tortoise placed under oil lived from twenty-four to thirty-six hours. Frogs die in less than an hour when placed under oil; in water impregnated with air they live a long time, respiration being carried on by the skin. Edwards says that toads, which he confined in baskets and placed in the Seine, lived several days; and Spallanzani and Edwards (*Meckel's Archiv.* v. 141. *Influence of Phys. Agents on Life*, p. 31,) have found them live a few hours even in water deprived of its air. I have wholly removed the lungs of frogs, after tying them at their root, and the animals still lived about thirty hours, respiration being performed most probably by means of the skin. In the experiment mentioned above, the frog placed in pure hydrogen showed distinct signs of life at the end of twelve hours, and respired from time to time, and after twenty-two hours was still only in a state of asphyxia. In experiments instituted by Humboldt and Provençal, gold fishes lived an hour and forty minutes in water deprived of its air by long boiling; and although in water impregnated with carbonic acid, and in carbonic acid gas, fishes died in a few minutes, the same observers found them live five hours in nitrogen and hydrogen, in which they kept their gill-covers closed.

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* The numbers quoted by the author, although mentioned by Sir H. Davy, in his different experiments, are not those which he considered most accurately to indicate the capacity of his lungs. They were 251 cubic inches in a state of voluntary inspiration; 135 in a state of natural inspiration: 118 after a natural expiration; and 41 after a forced expiration. This capacity Sir H. Davy considered below the medium, his chest being narrow.

The lower animals differ very much in the degree in which respiration is necessary to them; but, generally speaking, it appears not to be essential for the maintenance of their life. Carradori states that insects die immediately when immersed in oil, and according to Treviranus they may be killed very quickly by merely smearing the openings of the respiratory organs with oil. Biot, however, found insects of the genera Blaps and Tenebrio live eight days under the air-pump in air rarefied to a tension of from one to two millimetres. The larvæ of the gad-fly, in Schroeder van der Kolk's experiments, lived a considerable time in irrespirable gases. The larvæ of some insects live in putrefying vegetable and animal substances, and seem to have little need of pure oxygen, although no insect is known which has not a system of tracheal tubes, and which, therefore, during life does not respire air. Berzelius saw larvæ living in spring-water which contained carbonate of iron and some sulphuretted hydrogen. Leeches seem to live a long time without fresh water; while Tiedemann found that Holothuriæ die in a single day if the sea-water in which they are kept is not renewed. Intestinal worms, which inhabit other living beings, seem to dispense with respiration.*

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* For an account of the respiration of hybernating animals refer to page 77-8. The respiration of ova will be treated of in the third chapter of this section. The best works of reference on the subject of respiration in general, are—Goodwyn on the Connection of Life with Respiration, London, 1788. Lavoisier and Seguin, Ann. d. Chim. 91, 318. Menzie's Tentamen Physiol. de Respirat. Edinb. 1790. Crell, Ann. 1794, ii. 33. Sir H. Davy, Researches on Nitrous Oxide, Gilbert's Ann. 19, 298. Pfaff, in Gehlen J. de Chem. v. 103. Provençal et Humboldt, Schweigger's Jour. i. 86. Mém. d'Arcueil, t. ii. Edwards, Ann. de Chim. et de Phy. 22, 35; and Influence of Physical Agents, &c. Dulong, Schweigger's Jour. 38, 505. Despretz, Ann. de Chim. et de Phys. 26, 337. Spallanzani, Mém. sur la Respiration, Génève, 1803. Hausmann, de Anim. Exsang. Resp. Hannover, 1803. Sorg, de Resp. Insect. et Verm. Rudolstadt, 1805. Nitzsch, de Resp. Anim. Viteb. 1808. Nasse, Meckel's Arch. ii. 195, 435. Treviranus, Zeitschr. für Physiol. iv. 1.

CHAPTER II.

OF THE RESPIRATORY APPARATUS GENERALLY.

MANY of the lower animals appear to respire by their entire surface. When a determinate portion of the external membrane destined to effect certain changes in the air, or in the water impregnated with air, which comes in contact with it, is developed within a small space into a great extent of surface, so as to render the contact with this air or water more extensive, it constitutes a respiratory organ.

Different forms of the respiratory organ.—The development of the respiring surface may take place either towards the interior of the body in the form of ramified or sacculated cavities called lungs, or towards the exterior in the form of lamellated, ramified, pectinated, tufted, ciliated, or pinnated processes, called branchiæ, in which nature seems to have exhausted all imaginable varieties of form in the increase of surface towards the exterior. In the third kind of respiratory organ, the increase of surface for the contact of the air and the animal textures is obtained by the development of a system of tracheal tubes, ramified to extreme fineness, and spread through the most minute portions of all the organs of the body. This is the tracheal system of insects, and some of the Arachnida. The lungs generally respire air; there are, however, exceptions to this; for instance, the respiratory organ of the Holothuria consists of a tube ramified in an aborescent form, in which the respiratory function is performed by water being taken into the tubes, and again expelled from time to time. In animals provided with branchiæ or gills, the respiration is generally effected by means of water, but sometimes by air, as is the case in the terrestrial Crustacea.

Lungs and branchiæ, in their extreme forms, are completely distinct, but they often approach each other in their essential characters so nearly that it is difficult to determine to which type the organ belongs. Thus, the gills of the Cyclostomata, and of the sharks and rays, are enclosed in sac-like cavities, and the branchiæ of the Asidia form a branchial sac; but the characters of the two kinds of organs are still more confounded together in the pulmonary Arachnida, in which the respiratory organs have the characters both of lungs and branchiæ at the same time; and when Treviranus called them branchiæ, and I named them lungs, we were perhaps both equally correct or incorrect. In some insects, too, there is a mixed form of respiratory organ, partly branchial, partly tracheal.

In the *Infusoria* the only respiratory organs seem to be delicate cilia, with which, in many species, the surface is in part or wholly occupied; they are so minute that it requires the highest magnifying powers to see them.

Among the *Echinodermata*, the respiratory organ of the Holothuria is remarkable; it is a tube ramified in an arborescent form with terminal cellules, respiration being performed by the contact of water, taken in by the main tube, with the inner surface of the organ.

In the Annelida the respiratory organs are sometimes tufted branchiæ of a branched form, as in the Arenicolæ, and similar organs exist on the feet of the Nereides.

Among the *Mollusca* some breathe in the water by means of branchiæ, others by lungs in the air.

In the *Crustacea* the organs of respiration are branchiæ, and the function is, in nearly the entire class, performed in the water.

The *Arachnida* are divided into the pulmonary and the tracheal Arachnida. The respiratory organs of the first order are situated at the under surface of the abdomen. They are small sacs opening externally, each by a separate stigma. The aquatic Arachnida respire the air which is confined among the hairs of their body when they descend into the water.

All insects have a system of ramifying tracheæ, and in the greater number the respiration is aerial, the air being inhaled through a series of stigmata, which are generally situated at the sides of the rings of the abdomen.* From the stigmata the air is carried by the tracheæ, in some insects, into vesicles from which the rest of the tracheal tubes arise; in others, into longitudinal trunks, which ramify throughout the most delicate parts of the animal. In several insects, particularly in the Orthoptera, there are distinct respiratory movements—alternate dilatation and contraction of the abdomen.

The larvæ of many insects breathe by means of branchiæ in the water; and some insects, which in the larval state are aquatic, likewise respire water when they have attained their perfect condition, although they have an internal tracheal apparatus.

Respiratory organs of fishes.—In the osseous fishes there are four gills on each side, supported by the same number of long branchial arches. Each gill consists of a double series of lancet-shaped lamellæ attached to the branchial arch, like the teeth of a comb to its back. These lamellæ are frequently united for some distance at their base; they give off at right angles smaller lateral lamellæ. Each of the four branchial arteries, commencing its course at the inferior extremity of the branchial arch, runs in a groove along the convex border of the arch to its upper extremity, gradually diminishing in size; the veins run parallel with the arteries, but in the opposite direction to them, becoming larger as the latter become smaller, and, meeting on the vertebral column, unite to form the aorta. Each branchial artery gives off in the course just described, as many branches as there are branchial lamellæ. These branches bifurcate twice, and terminate in the lateral capillary vessels of the smaller lamellæ, in which the veins take their rise and run in a corresponding manner on the opposite side of the branchial lamellæ.

Branchiæ of Amphibia.—The respiratory organs of the tadpole are branchiæ. There is a branchial cavity on each side, and each cavity contains four branchial arches, from which branchial lamellæ arise. The branchial cavity on the right side is completely closed in by the skin; on the left side a small opening is left. The anterior extremities are developed in the branchial cavities.

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* See the representations of the tracheal system of many insects by Marcel de Serres, Isis, 1819, iv.

The larva of the salamander has external gills, with four branchial clefts. The Proteus family have also external branchiæ, three in number, attached to branchial arches. In the Siren there are three branchial clefts on each side, in the Proteus two, and in the Axolotl four. The Proteus family, throughout life, as well as the larvæ of the salamander and frog, in the second stage of their development, have both lungs and branchiæ, and consequently respire both air and water. From the aortic arches, or division of the main artery, the branchial arteries arise; and in these arteries the branchial veins terminate.

The lungs of reptiles and Amphibia are essentially mere sacs, of which the internal membrane is developed into folds, forming cells, so as greatly to increase the extent of surface. In most Amphibia there is a membranous trachea leading to the lungs, but it is generally very short; in the anourous Amphibia the larynx leads almost immediately into the membranous bronchi. The first appearance of the cartilaginous plates of the bronchi is in the Dactylethra, in which they form very irregularly branched and even perforated lamellæ, having no resemblance to bronchial rings. In the Pipa, which is allied to the Dactylethra, cartilaginous rings are met with. The bronchus of the Cæciliæ has regular rings of cartilage.

In the true reptiles the respiratory surface is extended by increase of the number of cells in the interior of the lungs.

In *birds* the lungs do not occupy the greater part of the thoracic cavity, as in Mammalia. They lie at the posterior part, intimately connected with the ribs and bound down by the serous membrane, which lines the common cavity of the abdomen and thorax; for in birds the diaphragm is not developed. On the surface of the lungs there are openings, through which air passes from the bronchi into large cells, situated around the pericardium and between the viscera of the abdomen. The bird can distend these cells with air, but cannot by that means render itself lighter for the purpose of flying.* The cells communicate again with the cavities of the bones, the majority of which are filled with air. The body of the bird is thus, of course, rendered specifically lighter than if its bones contained medulla. When a bird descends from a great elevation, where the air is rarefied, into a denser atmosphere, the air within its body very soon acquires the same tension as the surrounding atmosphere. Another peculiarity in the structure of the lungs in birds is, that their bronchi terminate in short blind cylindrical tubes, which lie side by side and have cellular parietes. In the embryo of the bird these tubes are still more distinct and more separated from each other, and have terminal dilatations. Retzius (*Froriep's Not.* 749) remarks, likewise, that the small bronchial tubes in birds communicate with each other.

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* This was shown by Kolhrausch, De Avium Saccorum Aëriorum Utilitate. Göttingen, 1832.

In man and Mammalia the structure of the lungs is essentially different. The minute bronchi have not the cellular parietes which we have described in birds, but terminate each in a distinct cell. These cells, or air vesicles, do not communicate one with another, their only opening is that of the minute bronchial twig which leads into each. Reisseisen (*De Fabricâ Pulmonum.* Berol. 1822,) has described a small artery, with its accompanying vein, going to each of these cells and forming around it a capillary network, which is so close that the diameter of the meshes is scarcely so great as that of the small vessels which form it. The diameter of a pulmonary vesicle is twenty times greater than that of one of the capillaries which are distributed in its parietes. As the diameter of the pulmonary artery is ⅙th smaller than that of the aorta,—their diameters being in the proportion of five to six,—the sectional area of the pulmonary artery, in comparison with that of the aorta, must be in the proportion of twenty-five to thirty-six, or of about two to three. If, therefore, the smallest divisions of the pulmonary artery bear the same proportion to the trunk, as the capillary vessels of the body bear to the aorta, the aggregate sectional area of the capillary vessels of the lungs ought to equal two-thirds of the aggregate sectional area of the capillaries of the rest of the body. It is very improbable, however, that this is the case; consequently the increase of capacity with which the ramification of the arteries of the body is attended, must be much greater than that which takes place in the ramification of the pulmonary artery.

Respiration is effected by the contact of the air with the blood, the smallest particles of which, in its passage through the innumerable capillaries ramifying on the cells of the lungs, are, by means of the immense surface which all these cells offer, exposed to the action of the atmosphere. The chemical process which ensues between the air and the blood, is carried on through the delicate membranous parietes of the cells, in accordance with the laws developed at pages 249–252.

CHAPTER III.

OF THE RESPIRATION OF MAN AND ANIMALS.

1. *Of respiration in the Air.*

Changes produced in the air by respiration.—The earliest accurate experiments on respiration are those of Lavoisier and Seguin. They found that the air expired contained more carbonic acid and water, and less oxygen, than that which was inspired; the amount of carbonic acid gained being somewhat less than that of the oxygen which had disappeared. It being known that one volume of oxygen united with its proportional of carbon, forms one volume of carbonic acid, it was conceived that the greater part of the oxygen had united with the carbon of the blood, so as to form carbonic acid, which was expired in the gaseous form; while the rest of the oxygen, combining with hydrogen contained in the blood, had given rise to the watery vapour which is exhaled from the lungs in considerable quantity. Taking the mean result of the experiments of Lavoisier, Menzies, Abernethy, Thomson, and Hales, it would appear that the quantity of watery vapour exhaled by an adult in twenty-four hours amounts to 7963 grains. This water contains some animal matter. (*Gmelin's Chemie*, iv. p. 1524.)

Quantity of carbonic acid generated.—Sir Humphry Davy having ascertained that a portion of air, which measured 161 cubic inches, was composed of 117 cubic inches nitrogen, 42.4 cubic inches oxygen, and 1.6 cubic inch carbonic acid, respired it for the space of a minute, during which time he performed nineteen respirations. At the termination of the experiment he found the air to consist of 111.6 cubic inches nitrogen, 23.0 cubic inches oxygen, and 17.4 cubic inches carbonic acid. Consequently 15.8 cubic inches of carbonic acid had been generated in his lungs in one minute. (*Sir H. Davy, Researches on Nitrous Oxide*, p. 435.)

Messrs. Allen and Pepys* afterwards investigated the subject in an admirable manner. The air was inspired from one gasometer and expired into another. As the mean result of their numerous observations they adopt their eleventh experiment, in which 302 cubic inches of carbonic acid were exhaled in eleven minutes, or about 27.2 cubic inches in one minute. After frequent repetition of their experiments, they found that air, after being once respired, contains 8 or 8½ per cent. of carbonic acid; and that however often the same air is respired, even if until it will no longer sustain life, it does not become charged with more than 10 per cent. of this gas.

Allen and Pepys ascertained, moreover, that a man respiring oxygen generates more carbonic acid than when breathing common air. Thus, for 100 parts of oxygen inhaled, 12 parts of carbonic acid were expired, and a considerable quantity of nitrogen was developed at the same time.

Gmelin (*Chemie*, iv. 1525,) has collected the results of the different experiments of Davy, Berthollet, Allen and Pepys, Menzies, and Prout; and, taking the mean of all these, it would appear that 100 parts of air, once respired, contain 5.82 parts of carbonic acid.

Dr. Prout's (*Ann. Phil.* vol. ii. p. 330; and vol. iv. p. 331—334,) experiments seem to show that the quantity of carbonic acid generated in a given time is greatest between the hours of eleven, A. M., and one, P. M.; smallest between the hours of half-past eight, P. M., and half-past three, A. M. If the quantity of carbonic acid generated in respiration is from any cause increased for a period, it afterwards sinks in the same proportion below the usual quantity. The amount of carbonic acid exhaled by the same person is diminished by depressing passions, by violent exercise, by taking spirituous liquors, tea, or vegetable food, and by the long-continued use of mercury. Carbonic acid is exhaled in larger quantity when the barometer is low.

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* Philos. Transact. 1808, 1809. Schweigger's Journal, t. 1; and Meckel's Archiv. iii. 232.

The quantity of carbonic acid formed by the process of respiration in twenty-four hours, was calculated by Lavoisier and Seguin to be 14,930 cubic inches, or 8534 grains; Davy estimated it at 31,680 cubic inches, or 17,811 grains; and Allen and Pepys at 39,600 cubic inches, or 18,612 grains. The quantity of carbon thus removed from the blood would be, consequently, according to Lavoisier's calculation, 2820 grains; according to Davy's estimate, 4853 grains; and 5148 grains, according to the calculation of Allen and Pepys. In all these calculations, the quantity of carbonic acid is, as Berzelius remarks, evidently too great; for the solid food taken into the body contains three-fourths of its weight of water, and of the other fourth seldom more than half is carbon; consequently, six and a quarter pounds of solid food would be necessary to supply the quantity of carbon which, according to these estimates, is excreted from the body by the lungs in twenty-four hours, independently of what is got rid of in other ways.

Amount of oxygen consumed.—Davy, Pfaff, Berthollet, and Allen and Pepys, all agree that the air, once respired, is diminished in volume. Allen and Pepys attributed this loss, which they estimated at not more than $\frac{1}{322}$ of the whole, to accidental circumstances. When the same air, however, is respired repeatedly as long as it can be borne, the diminution in volume is very distinct; for, taking the mean of the estimates which have been given by Lavoisier, Goodwin, Davy, Allen and Pepys, and Pfaff, it would be $\frac{1}{24}$th of the volume of the air inspired. (*Gmelin's Chemie*, iv. p. 1525.)

The results of most experiments which have been made on the subject seem to leave no doubt that less carbonic acid is formed during respiration than will replace the oxygen which disappears. Allen and Pepys, who are the only observers that failed to perceive this difference during ordinary respiration, did not consider that atmospheric air already contains a small proportion of carbonic acid, which alone would make a considerable difference in the results.

Is the proportion of nitrogen in the air changed by respiration? During the respiration of man and of the higher animals, the nitrogen of the atmosphere seems to be, under some circumstances, absorbed, and under others exhaled.

The conclusion to be deduced from all the experiments on this subject, seems to be, that during respiration nitrogen is both absorbed and exhaled by the blood; and that it is from the exhalation of the nitrogen being counterbalanced by its absorption, that this exhalation is not observed, except when the air respired itself contains no nitrogen. The discrepancy in the results obtained by different experimenters in regard to this point, is explained by M. Edwards,* by supposing that under certain circumstances the absorption of nitrogen is most active, under other circumstances the exhalation.

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* Ann. de Chim. et de Phys. 22, 35. Influence of Physical Agents, &c., pp. 226—229.

M. Collard de Martigny, (*Journ. de Physiol.* 1830,) who found an increased proportion of nitrogen in air which had been respired, also observed an exhalation of nitrogen by the skin. On the ground that nitrogen, like all other gases, is imbibed by moist animal membranes and by the skin, M. Collard assumes that the absorption and exhalation of nitrogen go on at the same time in the lungs, but that the exhalation is the more active. Berzelius (*Jahrb.* iv. 217,) regards the idea of a simultaneous exhalation and absorption of nitrogen as absurd.

Respiration of cold-blooded animals.—I have instituted several experiments on frogs, to ascertain the quantity of carbonic acid formed by the respiratory process in these animals. Their results, together with those of three experiments by M. Edwards, (*Influence of Physical Agents, &c.*,) afford 0·57 cubic inch, or rather more than half a cubic inch, as the quantity of carbonic acid formed by the respiration of a single full-grown frog in six hours.

From the results of my three experiments, I have again calculated the quantity of carbonic acid formed in 100 minutes for every 100 grains of the animal; and comparing the numbers thus obtained, with some experiments on frogs and toads by Treviranus, (*Zeitschrift für Physiol.* iv. H. i. p. 23,) who had reduced his results to the same conditions of temperature and atmospheric pressure, and also calculated them for 100 grains of the animal, and for 100 minutes of time, it would appear that for every 100 grains of a frog or toad, $\frac{1}{20}$th of a French cubic inch of carbonic acid is formed in 100 minutes.

Treviranus has investigated in an excellent manner the respiration of the lower animals, also, and reduced the results to the same standard with regard to heat, atmospheric pressure, time, and weight of the animal, as in his experiments on frogs and toads; and from his calculation it appears that, in proportion to their weight, invertebrate animals generate as much carbonic acid as the Amphibia.

Comparison of the products of the respiration of cold-blooded and warm-blooded animals.—From the results obtained by different observers, in experiments on the respiration of birds and Mammalia, Treviranus has calculated the amount of carbonic acid formed, and of oxygen absorbed, for every 100 grains weight of each animal during the space of 100 minutes.

Taking the mean of the data afforded by his table, it appears that for every 100 grains weight of a mammiferous animal, 0·52 French cubic inch [0·62 Engl. cub. in.] of carbonic acid is formed in 100 minutes, and for every 100 grains of birds, 0·97 French cubic inch [1·16 Engl. cub. in.], in the same space of time. We have already seen that, according to the results of the experiments of Treviranus and myself, 0·05 French cubic inch [0·06 English cub. in.] of carbonic acid are exhaled by frogs and toads in 100 minutes for every 100 grains of their weight; consequently the quantity of carbonic acid generated by cold-blooded animals is 10 times less for the same weight of the animal, than is formed by the respiration of Mammalia, and 19 times less than is generated by birds.

Treviranus has found, that in most insects the carbonic acid generated by respiration is, in proportion to their weight, in as great quantity as in Mammalia, although in some cases it approaches the proportion observed in Amphibia. The small amount of animal heat developed by insects cannot, then, be explained by the proportion of the carbonic acid formed in the respiratory process; but Treviranus supposes that their low temperature may arise from heat becoming latent in them during the development of the nitrogen, which they exhale in large quantity. It appears however from the experiments of Mr. Newport,* that the amount of heat generated by insects has, hitherto, been much underrated.

But even if the results of experiments on insects be rejected on account of their being subject to error from the small size of the animal, still, even in the case of Mammalia and Amphibia, the difference of temperature cannot, with any probability of truth, be referred to the difference in the quantity of carbonic acid generated in the two orders of animals.

The experiments of Treviranus seem to show that the generation of carbonic acid by the lower animals, is influenced by the temperature of the medium in which they respire. At 81½° Fahr. a honey-bee exhaled nearly three times as much carbonic acid as it did at 58½°. In general, the carbonic acid generated during respiration in the open air was insufficient to replace the oxygen absorbed. The quantity of oxygen consumed in the respiration of cold-blooded animals was often three times as great as that of the carbon exhaled.

Molluscous animals, however, do not merely extract all the oxygen from the air in which they are placed; they continue after this to exhale carbonic acid. Treviranus observed in all his experiments on the lower animals that nitrogen was exhaled, and in a few cases its quantity even exceeded that of the carbonic acid formed.

2. OF RESPIRATION IN WATER.

Changes produced in the water by the respiration of fishes.— The question of the exhalation or absorption of nitrogen during respiration is rendered still more complicated by the fact observed by Humboldt and Provençal, namely, that fishes absorb a considerable quantity of azote from the water in which they respire. Some fishes were kept during eight hours and thirty minutes in 4000 cubic centimetres of water. Before the experiment 2582 parts of the water contained 524 parts of air; after the experiment the same quantity of the water yielded only 453 parts of air. Humboldt and Provençal attribute this loss of 71 parts of air to the effect of respiration; and from the difference of the constitution of the air before and after the experiment, they calculate the proportion of the gases which had been absorbed or exhaled.

The experiments of the same physiologists show, moreover, that fishes absorb more oxygen than is replaced by the carbonic acid exhaled, which amounts, at most, to $\frac{4}{5}$ths, and frequently to $\frac{1}{2}$ only, of the oxygen absorbed.

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* See page 87, and Mr. Newport's paper on the respiration of insects in the Philos. Trans. for 1832.

It appears, from their researches, that fishes in rivers are, with reference to the quantity of oxygen in the medium which they respire, in the same condition as an animal breathing in an atmosphere that contains less than one per cent. of oxygen; for water never contains more than $\frac{27}{2000}$ of its volume of air, of which 31 per cent. is pure oxygen.

Mammalia appear to generate fifty times more carbonic acid than fishes.

Respiration of fishes by the skin.—Fishes absorb oxygen and exhale carbonic acid, not merely with their gills, but with the whole surface of their body, as long as they are surrounded with water impregnated with atmospheric air, but not when they are exposed to the air itself.

Respiration of fishes in the air.—As long as the gills are kept moist, fishes will continue to respire in the air, and will absorb exactly the same quantity of oxygen as by respiration in the water. Aquatic respiration differs then from respiration in the air less essentially than might at first appear. A moist surface is necessary even in pulmonary respiration.

Ermann states that the Cobitis fossilis, which lives chiefly in the mud, comes to the surface to swallow air, which subsequently undergoes in the intestines the usual changes produced by respiration, and is afterwards evacuated by the anus. The *swimming bladder* of fishes also contains air, of which one component is oxygen; but this air is not derived from without; it is secreted by the inner surface of the sac. The proportion which the oxygen bears to the nitrogen is sometimes greater, sometimes less, in the air of the swimming bladder than it is in the atmosphere. In many fishes, as in the carp, the air-bladder communicates with the pharynx. The tube which leads from the air-bladder sometimes opens into the pharynx by a wide orifice; sometimes, as in the carp, the opening is so narrow that no air can enter the tube from the pharynx, and it is, probably, only when the bladder is much distended that any air can force its way out of it. In many fishes the communication does not exist at all, and in them there is usually a red vascular and peculiar tissue in the walls of the bladder, destined for the secretion of the air; and even when the air-bladder does communicate with the pharynx, it is most probable that the air is thus secreted. Rupture of the air-bladder does not always deprive the fish of the power of maintaining its balance, —the fish does not always fall upon the side. The air-bladder is probably intended to enable the fish to alter its specific gravity, which it may do by compressing the air by means of the abdominal parietes, or on the other hand, by increasing the distension of the bladder. (See G. Fisher, über die Schwimmblase der Fische. Leipz. 1795. G. R. Treviranus, Vermischte Schriften, 2 bd. 156.)

Many animals which respire by means of branchiæ in the water, produce remarkable currents in the water around the branchiæ.

These currents are now known to be produced by the vibration of minute cilia, and the phenomenon is called ciliary motion. (*See the Chapter on Ciliary Motion.*)

3. OF THE RESPIRATION OF THE EMBRYOS OF ANIMALS.

The embryos even of frogs and toads, of sharks and rays, and of the sword-fish, are provided with external branchiæ for aquatic respiration.

The ova of oviparous animals during their development effect the same changes in the surrounding air as the adult animals; and they are not developed, if the supply of atmospheric air, or of water impregnated with it, is prevented.

Respiration of the embryos of birds and insects.—The embryo in the egg of the bird perishes, if the shell is covered with varnish or oil. In warm water also the development of the egg of birds is not maintained, nor in irrespirable gases according to Viborg's experiments. (*Abhandl. für Thierärzte und Œconomen.* iv. 445.) Schwann has shown that when eggs of the common hen are kept at the proper temperature in gases which contain no oxygen, although the enlargement of the germinal membrane, its division into the serous and mucous layers, and the formation of the *area pellucida*, take place, yet neither blood nor embryo is formed.

Atmospheric air has such free access to the ovum through the pores of the shell of the bird's egg, that it is almost impossible for the air not to be acted on by the blood in the vessels of the allantois, the chief function of which would indeed seem to be to bring a large number of blood-vessels as near the surface as possible.

Respiration of the embryo of Mammalia.—The first stages of the development of the ovum of Mammalia take place not merely without the access of atmospheric air, but even before the ovum has any connection with the parent, and when it is merely surrounded by the secretions of the uterus. At no period of their development do the embryos of Mammalia respire in the ordinary sense of the term; but the function of respiration is in them supplied by their connection with the parent animal. E. H. Weber has demonstrated by some very interesting dissections the manner in which the placenta and uterus are connected in the human subject, and has shown that in man, as well as in ruminating animals, no direct communication exists between the vessels of the fœtus and those of the mother.

There are several circumstances which render it probable that the placenta performs a function analogous to the respiration of the ova of oviparous animals.

Thus, in the first place, interruption of the circulation in the umbilical vessels causes the death of the ovum; secondly, respiration is necessary to the ova of oviparous animals, and is effected by the allantois membrane, which receives the same vessels, as the chorion of the ovum of man and Mammalia, namely, the umbilical vessels; and the third circumstance is, that in the same order of animals, both oviparous and viviparous genera occur. Thus the ova of the majority of serpents and lizards are developed in the air; the ova of the Lacerta crocea, of the blind worm, and vipers, in the oviduct. Even in the ova of the lizard the development of the embryo is far advanced before the eggs are deposited. These and many other analogous facts concur in showing that the conditions under which the embryos of oviparous and viviparous animals are developed, do not greatly differ; and thus support the supposition that the placenta of Mammalia serves the purpose of respiration.

There is, however, no perceptible difference of colour between the blood of the umbilical arteries and that of the umbilical veins in the human fœtus, or in that of mammiferous animals. Many female sheep are slaughtered at Bonn; so that during the first part of the winter the embryo of sheep and even of cows can be obtained easily, together with the uterus, and often while they are warm. During the winter such parts were brought to me regularly for anatomical purposes, and I have not a second time observed a distinct difference in the colour of the blood of the umbilical veins and arteries. E. H. Weber (*Hildebrandt's Anat.* Bd. iv. 524,) also denies that this difference exists, and those who practise midwifery have not observed it.

The blood of the umbilical vessels of the fœtus, like the venous blood of the adult, is reddened by exposure to the air. This I have frequently observed: it may, perhaps, as Fourcroy has pointed out, take place a little slower and in a less marked degree than venous blood. The blood of the umbilical vessels and that of the fœtus also coagulate less firmly than that of the adult. It appears that the blood of the fœtus, both arterial and venous, differs in no perceptible respect from the venous blood of the adult.

Does the liquor amnios serve the function of respiration?—Some physiologists have maintained that the liquor amnios with which the fœtus is surrounded, serves the purpose of respiration through the medium of the skin; or they have even supposed it to be respired by the lungs, because some of the fluid has been found in the trachea. (*Scheel, De liq. amnii nat. et usu.* Hafn. 1799.) The experiments which I made when a student,—and have since most carefully repeated,—showing that fishes die as quickly in the liquor amnios of the cow and sheep as in oil,—namely, within forty minutes,—while in the same quantity of Rhine water they live a long time, are sufficient to indicate that the liquor amnios cannot serve the purpose of respiration.

CHAPTER IV.

OF THE CHANGES WHICH THE BLOOD UNDERGOES IN THE LUNGS.*

Its colour.—By respiration the blood is rendered of a bright red colour. The same change of colour is produced by agitating blood with oxygen, and on the surface of venous blood by mere exposure to the air. This bright scarlet colour may also be given to blood by the admixture of sugar, or of neutral salts,—such as nitrate of potash, sulphate of soda, sal-ammoniac, muriate of soda, and carbonate of potash. Solution of potash, according to my observation, changes the colour of blood to brown, although the contrary is erroneously asserted in some works. Thenard and Huenefeld state that the blood acquires a cherry-red colour when exposed to an atmosphere of ammonia. Chlorine changes its colour first to brown, then to white; by acids generally it is rendered brown; but carbonic acid first darkens its red colour, then changes it to violet, and at last renders it almost black. Wedemeyer says, that prussic acid brightens the red colours of the blood; but Hertwitch (*Froriep's Notiz.* 759,) asserts that it darkens it. Stevens found the colour darkened by sulpho-cyanic acid. Carbonic oxide, carburetted hydrogen, and nitric oxide, are stated by Huenefeld to change it to violet; while nitrous oxide and hydrogen, he says, render it purple, or red brown. I have agitated blood with hydrogen gas, but could perceive no change of colour. Berzelius found that the colour of blood, which was already somewhat darkened, was rendered brighter by carburetted hydrogen. It appears, then, that the colour of the blood is changed with great facility by various substances.

Difference between arterial and venous blood.—The specific gravity of arterial and that of venous blood were found by Dr. J. Davy to be very nearly equal,—namely, in the proportion of 903 for the former to 913 for the latter.† According to the same observer, the capacity for caloric of the former as compared with that of the latter, is as 10·11 to 10·10.

The temperature of arterial blood is stated by Dr. J. Davy to be 1° or 1½° Fahr. higher than that of venous blood. This is confirmed by Krimer and Scudamore; other observers have perceived no difference of temperature. (See *Burdach's Physiol.* iv. 382.) Autenreith, Mayer, Davy, Berthold, and Blundell, agree that arterial blood coagulates more quickly than venous blood: while Thackrah has observed the contrary. Mayer, Blainville, and Denis state, that venous blood yields somewhat less serum and more coagulum than arterial blood. Arterial blood, according to Mayer's observation, contains more fibrin than venous blood, and yields it in thicker, solid, and shining bundles; in which statement he agrees with Emmert. The results of the experiments of Berthold and Denis, and of one experiment which I performed with the blood of a goat, have been detailed at page 157; taking the mean of these results, it appears that arterial contains more fibrin than venous blood in the proportion of 29 to 24. The greater softness of the fibrin obtained from venous, as compared with that from arterial blood, might induce the supposition that the fibrin undergoes some farther development in the respiratory process; but the difference in consistence may be explained by the circumstance of the fibrin existing in smaller proportion in venous blood, in consequence of which its particles must be further separated from each other. The smaller proportion of the fibrin in venous blood arises wholly, perhaps, from a part of the fibrin of arterial blood being appropriated to the nutrition of the tissues during the passage of the blood through the capillaries; it may arise in part, also, from the lymph which contains fibrin in solution being poured into the vascular system near the heart.

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* From Original Researches.

† See Burdach's Physiol. Bd. iv. p. 381; and Dr. Davy in Phil. Trans. 1814.

It is, however, probable that respiration does contribute to the development of fibrin, and for these reasons:—First, that the blood of the fœtus contains a very small proportion of fibrin, though it is an error to say it contains none; and, secondly, that in the *morbus cæruleus,* which is dependent on malformations of the heart, such as persistence of the canal in the *ductus arteriosus,* or of the foramen ovale, tendency to hemorrhage (from deficient coagulability of the blood?) has been observed. The remarkable tendency to hemorrhage from small wounds, which is sometimes witnessed, is, however, an affection distinct from the morbus cæruleus. The assertion of Denis, (*Rech. exp. sur le Sang Humain.* Paris, 1830,) that venous blood contains less cruor than arterial blood, appears to me to be merely an hypothesis; for there is no means of estimating the number of red particles in any kind of blood. (See page 157.)

The evidence of different observers respecting the quantity of water in the two kinds of blood is quite contradictory.*

From various analyses it appears, then, that there is less carbon in the cruor of arterial blood than in that of venous blood, which would agree very well with the theory of the excretion of carbon in the form of carbonic acid by the lungs. Again, arterial blood contains more oxygen than venous blood; and this fact would seem to be in favour of the absorption of oxygen by the blood in the lungs. No value, however, can be set upon these facts till they have been found by repeated analyses to be constant, for a slight difference in the drying of the substances to be analysed may make a great difference in the results. (See also *Lecanu, Etudes Chimiques sur le sang Humain.* Paris, 1837.)

The halitus of the blood seems to be an important part of this fluid. But it is not known whether it differs in arterial and venous blood.

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* For an account of the different statements, see Burdach's Physiol. Bd. iv. 383.

Cause of the changes of colour which the blood undergoes.—Arterial blood acquires a dark colour while passing through the capillaries of the body, and its bright colour is again restored in the capillaries of the lungs. If, however, respiration is interrupted, the blood returns from the lungs with its dark venous colour unchanged; while, even after the death of an animal, if respiration is kept up artificially, the change in the colour of the blood in the lungs takes place as before. Division of the nervi vagi does not interrupt the process; indeed it is well known that blood out of the body is reddened by mere exposure to the atmosphere; and if oxygen is injected into the vessels of an animal, even the blood in the veins becomes of a bright colour.

The study of the causes of these changes will lead us to the theory of respiration and to the decision of the question, whether the carbonic acid expired during respiration existed previously in the blood, or whether it is formed by the union of the carbon of the blood with the oxygen of the air in the lungs.

The facts relative to this subject, which have been ascertained by experiment, may be stated as follows:—

1. The colour of venous blood is not rendered perceptibly brighter by exposure to the vacuum of the air-pump.

2. Blood artificially impregnated with carbonic acid also does not become of a bright colour when exposed to the vacuum of an air-pump.

3. Blood impregnated artificially with carbonic acid, and thus darkened, recovers its natural colour in some degree when exposed to the air.

4. Blood which has been rendered of quite a dark violet colour by being impregnated with carbonic acid, acquires a bright red colour when agitated with oxygen.

5. The oxygen in which blood impregnated with carbonic acid has been thus agitated, is afterwards found to contain carbonic acid mixed with it.

6. Carbonic acid is evolved likewise when fresh blood is agitated with atmospheric air.

7. No carbonic acid can be obtained from venous blood by the agency of heat.

8. Carbonic acid is set free when venous blood is submitted to the vacuum of the air-pump, or when hydrogen or nitrogen is passed through it. Vogel, Brande, Home and Bauer, Scudamore, and Clanny procured carbonic acid from blood in a vacuum.

Very opposite results were reached by Dr. J. Davy, Mitscherlich, Tiedemann and Gmelin, Strohmeyer, and myself.

Hoffmann (*Med. Gazette,* 1833) and Stevens (*Ibid.* 1834.—*Phil. Transact.* 1834), however, found that, although no carbonic acid could be extracted from the blood by mere exposure to a vacuum or heat, yet carbonic acid was evolved when the blood was agitated with another gas,—for instance, with hydrogen.

The observations of Stevens and Hoffmann have recently been confirmed by various experimenters. Bertuch and Magnus had satisfied themselves of their correctness some time since; and I have detailed the results of their experiments in the *Archiv. für Anat. und Physiologie*, 1836, p. cxxvii. Bischoff* has obtained the same result from some very accurate experiments. Gmelin also has now convinced himself of the existence of carbonic acid in the blood. The experiments of all these observers tend to prove that hydrogen as well as nitrogen, when made to pass through venous blood, becomes impregnated with carbonic acid gas; and, according to Professor Magnus, it is extracted in as large proportion by them as by atmospheric air. The quantity of carbonic acid taken up by hydrogen gas amounts to at least $\frac{1}{6}$th of the volume of the blood. Bischoff succeeded likewise in producing an evolution of carbonic acid from the blood by means of the air-pump, but in very small quantity. Magnus has found in repeated experiments that a perceptible quantity of carbonic acid is not given out until the air in which it is placed is so rarefied that it supports only one inch of mercury; and this explains why former observers had obtained an opposite result.

9. A certain quantity of gas can be extracted from arterial blood likewise by means of the air-pump, although none, that can be detected, is given out under the influence of heat.

Magnus ascertained that in a vacuum, arterial blood gives out a considerable quantity of gaseous matter, not less, in fact, than is evolved by venous blood.

10. Both kinds of blood contain carbonic acid gas, nitrogen and oxygen, but in different proportions; venous blood contains most carbonic acid, arterial blood most oxygen; the proportion of nitrogen in the two is not always different. This important result, which is decisive as to the theory of respiration, has been brought to light by the careful and accurate experiments of Magnus.

From these, it appears that the quantity of gas contained in the blood amounts in the mean to $\frac{1}{10}$th, and sometimes is as much as $\frac{1}{8}$th of the volume of the blood itself; that the oxygen in venous blood equals at most $\frac{1}{4}$th, and often only $\frac{1}{5}$th of the carbonic acid which the same blood contains; while in arterial blood the oxygen equals at least $\frac{1}{3}$rd and almost $\frac{1}{2}$ of the quantity of carbonic acid.

It must not be imagined, however, that these gases exist in the blood in an aeriform state; they are in a state of solution in it, just as the oxygen and nitrogen are in the water of rivers and lakes.

The changes of colour which the blood undergoes during its circulation suggests the idea, that the gases combine more especially with the red particles than with the fluid part of the blood. The red particles are constantly acquiring a bright scarlet colour in the lungs, and resuming their dark red colour in the capillaries of the rest of the body. It is possible, therefore, that they are the means of communicating the chemical changes which the blood undergoes in the lungs to the other organs of the body. But this is a mere supposition.

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* Commentatio de nov. quibusd. Experim. Chemico-physiol. ad illustr. theoriam de Respiratione institutis. Heidelb. 1837.

I have convinced myself by careful observation, that in the frog the red particles in arterial, do not differ in the slightest degree from those in venous blood.

11. No carbonic acid is evolved during the change of the colour of venous to that of arterial blood, which is produced by the admixture of neutral salts.

Dr. Stevens (*On the Blood*, London, 1832,) has made some interesting observations on the share which the salts of the blood have in producing its red colour.

12. The red coagulum of blood, when placed in distilled water, assumes a darker, in fact, a blackish colour.—Stevens found that a coagulum placed in distilled water, which extracts the salts, becomes dark, and recovers its scarlet colour on being immersed in a saline solution. Dr. R. Froriep (*Froriep's Not.* 759,) has confirmed this experiment. It succeeds in a vacuum as well as in the air. (*Müller's Archiv.* 1835, 119.) From this fact Stevens draws the inference that it is not the oxygen of the atmosphere, but the serum with its salts, which produces the bright colour of the blood; and hence it is, he says, that when the proportion of the salts in the blood is diminished, as in yellow fever and cholera, the blood is darker in colour, and does not acquire the arterial tint when exposed to the air, while it assumes it immediately on salts being added. And hence Dr. Stevens further infers that the natural colour of the cruorin is dark or blackish, and that it is red only while in contact with the serum. On this theory he accounts for the fact which he has observed, that a coagulum which has been immersed in distilled water, cannot, when exposed to the air, acquire the bright scarlet colour until dipped in a saline solution. The dark colour of venous blood is ascribed, by Dr. Stevens, to the carbonic acid which it is supposed to contain. If this supposition were correct, venous blood ought to become arterial under the air-pump, which is not the case, and also when exposed to hydrogen, for that gas allows of the exhalation of carbonic acid,—indeed, a bladder filled with hydrogen, and placed in carbonic acid, becomes distended to bursting. (See page 249.) However, without denying the necessity of the salts to the production of the arterial colour, it must be confessed, that when oxygen acts on the red particles of the blood surrounded by the saline serum, it gives rise to a brighter colour, without the proportion of the saline matter in the blood being altered. (See *Bischoff*, *loc. cit.*)

CHAPTER V.

OF THE CHEMICAL PROCESS OF RESPIRATION.

Conditions on which the process depends.—It would be a great error to suppose that the oxygen of the air permeates the parietes of the air-cells and the capillary vessels, to enter the blood during inspiration only, while during expiration the carbonic acid is exhaled through the membranes from the blood. The absorption of oxygen into the blood which is circulating in the capillaries of the air-cells, and the exhalation of carbonic acid from the same blood, go on simultaneously and uninterruptedly. The acts of inspiration and expiration have no correspondence with the chemical process; they are merely alternately motions of contraction and dilatation of the thorax and of the lungs. The latter organs are themselves never completely empty; they always contain some air, which consists partly of atmospheric air, from which the oxygen is being constantly absorbed, and partly of carbonic acid, which is as constantly being exhaled. By the act of expiration the greater part of the air chemically changed by the respiratory process, but not all of it, is expelled; by inspiration a supply of fresh air is drawn into the lungs.

In many animals the respiratory movements of the organs of respiration do not exist, and the constant chemical change only takes place; this is the case in the larva of the salamander, which breathes with external immovable branchiæ.

It is unnecessary to enter here into any explanation of the property by which the parietes of the air-cells of the lungs allow the oxygen of the atmosphere and the carbonic acid to pass through them,—the former to enter the blood, and the latter to be exhaled. The property of permeability to liquid and gasiform fluids has been shown, in Book II. page 249, to be possessed by all soft animal tissues, particularly by membranes. The process of endosmose or imbibition must go on with extrordinary rapidity through the delicate parietes of the air-cells of the lungs, and the blood circulating in the membrane forming the cells must participate in the process. Besides, the blood, or rather the red particles, have a remarkably strong affinity for oxygen; hence the rapidity with which venous blood, when exposed to the air out of the body, acquires an arterial colour; carbonic acid being at the same time exhaled. The constant change of dark to bright scarlet-coloured blood goes on in the lungs even after the pulmonary nerves—the nervi vagi—have been divided.

The distribution of the blood in such innumerable capillary vessels in the parietes of the air-cells, is then evidently intended to expose it more completely to the action of the air; the whole mass of blood sent to the lungs being, by this means, made to circulate on the vast surface of contact afforded by the air-cells. It is still doubtful whether the pulmonary tissue is endowed in a greater degree than other parts with a specific power of effecting a chemical change in atmospheric air; for the red particles themselves seem to act the main part in producing this change in the air, and similar changes take place on other surfaces of the animal body, as on the skin of fishes and frogs, and in the intestines of the Cobitis fossilis; moreover, the chemical process of respiration is not arrested by division of the pulmonary nerves. I have found, as Edwards had previously, that frogs will live thirty hours after their lungs have been removed, respiring by means of their skin; while, if immersed in water from which the air has been expelled by boiling, they die much sooner. The lungs, however, by virtue of their organization, by the delicacy of the membrane lining their cells, and the immense surface of contact afforded by them, are better adapted than any other parts for the performance of the chemical function of respiration.

Different *theories* have been advanced *to explain the chemical changes effected in respiration.*

1. According to the hypotheses of Lavoisier, Laplace, and Prout, the blood is constantly pouring into the air-cells, by exhalation, a fluid consisting chiefly of carbon and hydrogen, the union of which with the oxygen of the atmosphere gives rise to the carbonic acid and water that are expelled from the lungs by expiration. The existence of such a fluid, consisting of carbon and hydrogen, appears to be, in a chemical point of view, quite hypothetical. (See *Gmelin's Chemie*, iv. 1529.) Those who adopt this theory, suppose the production of animal heat to depend on the formation of carbonic acid and water in the cavity of the air-cells, not in the blood; it is necessary, therefore, to remark that the temperature of the lungs is generally not at all higher than that of other parts of the body.

2. The theory adopted by most chemists is that of Sir H. Davy, viz. that the air permeates the membranous walls of the air-cells, enters the blood, and in it becomes decomposed in consequence of the affinity of the oxygen for the red particles, while carbonic acid is formed, and escapes, in the gaseous form, with the greater part of the nitrogen. Sir H. Davy inferred, from the results of his experiments on the respiration of nitrous oxide and hydrogen, that a certain portion of the carbonic acid produced in respiration is evolved from the blood itself. According to this theory, the animal heat is supposed to be generated in the blood which is circulating through the lungs. The observation of Dr. J. Davy, that the blood of the left cavities of the heart and of the arteries—the carotid—is warmer by 1°, or 1½°, Fahr. than the blood of the right cavities or veins—the jugular vein—is favourable to this theory.

3. Some physiologists, availing themselves of the fact that during respiration more oxygen disappears than is necessary for the production of the carbonic acid which replaces it, admit that the carbonic acid is formed in the lungs, or in the vessels of the lungs, by the direct combination of a part of the oxygen of the air with carbon of the blood, but suppose that the portion of the oxygen not engaged in forming carbonic acid, does not unite with hydrogen to form water, but becomes chemically combined with the blood, giving to it the

arterial colour; and that the red particles thus oxidised form the vital excitants of the tissues of the body. The fact of more oxygen disappearing than is accounted for by the carbonic acid formed, does not justify the assumption of Lavoisier, Laplace, Dulong, and Despretz, that this portion of oxygen which is lost, goes to form the watery vapour, by combining with the hydrogen of the blood. The hypothesis, that the watery vapour exhaled from the lungs is formed in them by the direct combination of its elements, is quite gratuitous; for under the existing external conditions water must evaporate from moist animal surfaces, particularly at the temperature of warm-blooded animals. The hypothesis of the generation of water in the lungs has, therefore, been merely invented to support their theory of combustion, but is not founded on any proofs. The experiments of Collard de Martigny showed that the watery vapour is always exhaled, whatever may be the gas respired; that it continues to be exhaled even in hydrogen gas, when, consequently, no oxygen is present to form it. This fact, however, is, in my opinion, not quite decisive of the question; because animals, when placed in these irrespirable gases, have always some atmospheric air in their lungs. Magendie[*] states that the exhalation of water from the lungs is increased when water, of the temperature of the body, is injected into the veins. The exhalation of water from the lungs, therefore, like the transpiration from the skin, must be regarded as a simple exhalation from the blood,—not, however, as a mere physical evaporation. But on this point I shall have occasion to speak in a subsequent section of this book. Since it appears then, that no formation of water directly from its elements takes place in the lungs, and since most experimenters on respiration, both in air and water, agree that more oxygen disappears than enters into the composition of the carbonic acid which is formed, the excess of oxygen absorbed must unite with the blood, and thus, probably, gives rise to the bright colour of arterial blood, and of blood exposed to the air. It is already known that a mixture of red particles and serum, or blood deprived of its fibrin by stirring, is rendered throughout of this bright colour by merely passing oxygen through it. The probability of the oxygen combining with the blood is strengthened by the observation, that when blood and air are agitated together, the volume of the oxygen absorbed much exceeds that of the carbonic acid formed. The experiments performed by Nysten, (*Rech. de Physiol. et de Chim. Pathol.*) which consisted in injecting gases into the veins of animals, and in which oxygen imparted the arterial colour to the venous blood, of course without any carbonic acid being evolved, are also in favour of this opinion.

4. According to the theory of Lagrange and Hassenfratz, the oxygen absorbed into the blood, in which it is merely in a state of solution, or combined in some way with the red particles, does not unite in the lungs with the carbon of the blood. Those chemists

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[*] Précis Elémentaire de Physiologie, 2nd edit. ii. 246. Translation by Dr. Milligan, p. 453.

supposed the combination to be accomplished in the course of the circulation, carbonic acid thus formed being retained in the blood, until, reaching the lungs, it is set free. Lagrange founded this opinion partly on the fact that arterial blood, contained in close vessels, after a time assumes spontaneously a dark colour. Now, since arterial blood does not lose its bright colour and become venous until it passes through the capillaries, the formation of carbonic acid, supposing the theory of Lagrange to be correct, can take place only in the capillary vessels of the body. In that case, the venous blood ought to contain principally carbonic acid in solution, and the arterial blood oxygen in some way loosely combined. This view of the respiratory process has been adopted by a great number of physiologists, and was chiefly supported by the experiments of Vogel, Home, Brande, Scudamore, and Collard de Martigny, which seemed to prove that venous blood really contains carbonic acid; and by the experiment of Sir H. Davy, from which he concluded that oxygen can be obtained from arterial blood by heat. It explains why the lungs are not warmer than other parts of the body. F. Nasse has, in an excellent treatise on respiration, (*Meckel's Archiv.* ii. 195, 435,) collected all the earlier facts supporting this theory. Experiments which yielded contrary results, and which we have already detailed, had thrown a doubt on the correctness of this view. But the observations of Stevens, Hoffmann, Bischoff, and Bertuch, [and lately of Dr. J. Davy,] who have shown that venous blood contains carbonic acid, and still more those of Magnus, who has demonstrated the existence of gas and its composition in both kinds of blood, have rendered this theory the most probable.

5. Dr. Stevens has recently advanced a new theory of the respiratory process, which at first view appears ingenious. According to Stevens, the colouring matter of the blood is itself dark, but is rendered scarlet by the salts of the serum. The natural colour of the blood, therefore, as long as it is in contact with serum, is bright red or scarlet; but if the coagulum of blood is dipped in water, the red colour becomes dark, on account of the serum with its salts being washed out of the coagulum by the water. The blood, naturally of a bright colour, is rendered dark by carbonic acid. Carbonic acid, Stevens says, is formed in the capillaries, hence the dark colour of venous blood; it is excreted in the lungs, and the natural bright-red colour of the blood is thus restored, the oxygen having no share in producing the change of colour. If Dr. Stevens's theory were correct, venous blood ought to become of a bright colour in the vacuum of an air-pump, from the escape of the carbonic acid; this, however, as we have already seen, does not take place. The oxygen, therefore, which is absorbed by the blood in the lungs, must be the essential cause of its arterial colour. De Maack* states that the red colouring matter of the blood is of a blackish colour, as well when it is impregnated with oxygen, as when it contains more carbonic acid,

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* De ratione quæ colorem Sanguinis inter et Respirationis functionem intercedit. Kil. 1834.

as long as it does not come into contact with a solution of neutral salts; but that salts render cruor of both kinds red,—the first of an arterial hue, the latter of the venous tint. De Maack confirms the observation of Berzelius, that serum absorbs only an extremely small quantity of oxygen, and evolves no carbonic acid. A solution of red colouring matter, on the contrary, measuring two and a half volumes, being brought into contact with two volumes of oxygen, absorbed one volume and a half, and afterwards, on a saline fluid being added, became of a bright red colour. De Maack imagines that the colouring matter which is impregnated with carbonic acid, is decomposed by oxygen, the colouring matter becoming oxydised while the carbonic acid is set free; just as carbonate of the protoxide of iron undergoes decomposition in moist air, being converted into hydrate of the peroxide.

6. According to another theory of the respiratory process, the carbonic acid cannot be generated by the union of the oxygen of the air with carbon of the blood, because the exhalation of carbonic acid goes on when gases containing no oxygen are respired, as was shown by the experiments of Spallanzani, on cold-blooded animals, since repeated with the same result by M. Edwards. It is supposed, therefore, to be formed from the ultimate elements of the blood, like other secretions. The secretion of different gases by the air-bladder of fishes may be adduced in support of this hypothesis; according to which, the carbonic acid would not necessarily exist already formed in the venous blood, but might be generated in the capillaries of the lungs independently of the concurrent action of oxygen. The existence of the gases in the blood itself, however, proves that they are not originally the product of a secreting action of the lungs.

7. Mitscherlich, Gmelin, and Tiedemann have lately proposed a perfectly original theory of respiration. The facts on which they ground their opinion are the following:—That acetic and lactic acid exist in the free or combined state in most secretions, and also in the blood; that these acids must be generated in the animal body itself, because they are contained in much smaller quantity in the food than in the cutaneous and renal secretions; and further, that, as they have ascertained, venous blood contains more alkaline sub-carbonates than arterial blood, the minimum amount of carbonic acid combined with alkalies contained in 100 parts of venous blood being 12.3 parts,—in the same quantity of arterial blood, only 8.3 parts. They suppose now that by the free contact of the blood with the air during respiration acetic acid is generated, which decomposes the alkaline carbonate of the venous blood, and sets free the carbonic acid,—that the oxygen of the inspired air unites, in part, directly with carbon and hydrogen, and forms carbonic acid and water, and in part enters into combination with the organic compounds contained in the blood; the result of which is that organic products which are necessary to life are produced; while, at the same time, other organic substances are converted into lower organic products, such as the acetic and lactic acids, which decompose a part of the carbonates contained in the blood, and expel the carbonic acid into the air-cells of the lungs. (*Tiedemann's Zeitschrift f. Physiol.* 5.)

While the existence of gases in the blood itself was doubtful, this was an ingenious mode of explaining the phenomena; but Gmelin himself has since recognised the existence of carbonic acid in the blood.

In determining the nature of the chemical process of respiration, all depends on the solutions afforded to the following questions:—

1. Does venous blood contain carbonic acid, and arterial blood oxygen? This question has been determined in the affirmative by experiments which we have already mentioned, particularly the excellent researches of Magnus.

2. Is the carbonic acid contained in the blood extracted from it by other gases as well as by atmospheric air? The experiments of Hoffmann, Stevens, Bischoff, Bertuch and Magnus have shown that this likewise is the case. Hydrogen and nitrogen, brought freely in contact with blood, become impregnated with carbonic acid in as large proportion as atmospheric air which has been passed through that fluid.

3. Is carbonic acid exhaled from the lungs of cold-blooded animals in an atmosphere of pure hydrogen or pure nitrogen? We shall see that this is most certainly the case.

Products of respiration in hydrogen and nitrogen.—The earlier observations of Sir H. Davy (*Gilbert's Annal.* xix. 320), Coutanceau, and Nysten (*Meckel's Archiv.* ii. 256), on this subject, are of no value; for warm-blooded animals, on which they were instituted, can be kept in hydrogen gas but a short time, and their lungs necessarily contain carbonic acid at the commencement of the experiment. No certain conclusions can be drawn from the experiments unless the animals are kept for a considerable time in the hydrogen or nitrogen, and unless the quantity of carbonic acid formed is large. M. Edwards (*Infl. of Physical Agents*, &c. Dr. Hodgkin's translation, p. 236,) and Collard de Martigny (*Magendie's Journal*, 1830, p. 121,) obtained such a result.

I thought it very requisite to repeat these experiments of Edwards and Collard; and, having twenty pounds of mercury at my disposal, I was enabled to perform them on a large scale. I have arranged the results which I obtained, together with those of some experiments by Professor Bergemann, in a tabular form.

			Volume of Carbonic Acid generated.	
Name of Observer.	*Gas respired.*	*Duration of Experiments.* Hours.	*In decimals of French cubic Inch.*	*In decimals of English cubic inch.*
Müller, . .	Nitrogen,	6	0·25	0·30
Bergemann, .	do.	14	0·75	0·90
Do. . .	do.	12	0·5	0 60
Müller and Bergemann,	Hydrogen,	22	0·5	0·50
Müller, . .	do.	6½	0·83	0·99
Do. . .	do.	6	0·33	0·39
Do. . .	do.	8	0·4	0·48
Bergemann,	do.	10	0·55	0·66
Do. . .	do.	12	0·8	0·96
Do. . .	do.	13	0·7	0·84
Do. . .	do.	14	0·5	0·60

It might still be objected to these experiments, that the frogs retained a certain quantity of atmospheric air in their lungs, and that their intestinal canal might also contain carbonic acid. I have, therefore, repeated the experiments in such a manner as to avoid these objections, exposing the frogs first to the vacuum of the air-pump, and then filling the vacuum with hydrogen. In one experiment I even removed this hydrogen again, by means of the pump, so as to get rid of every portion of atmospheric air, and the result was the same as before.

The quantity of carbonic acid, then, which a frog exhales in from six to twelve hours in gases that contain no oxygen, may be safely estimated at from $\frac{1}{4}$ to $\frac{4}{5}$ of a cubic inch French, from $\frac{3}{10}$ths to $\frac{96}{100}$ths of a cubic inch English. The capacity of the lungs and throat of a frog, on an average, is not more than $\frac{3}{8}$ or $\frac{1}{2}$ of a cubic inch, French, $\frac{9}{20}$ths or $\frac{6}{10}$ths of an English cubic inch; and in these experiments the lungs and throats were both compressed, so that they could not have contained much atmospheric air and carbonic acid, even if a small quantity had remained. The fact, therefore, which Spallanzani ascertained, cannot be disputed; cold-blooded animals continue to exhale carbonic acid even in gases which contain no oxygen, and in nearly as large quantity as when respiring atmospheric air; for it appears from experiments, that the average amount of carbonic acid generated by a frog breathing atmospheric air, is, in six hours, 0·57 of a French cubic inch, 0·68 of an English cubic inch.

These results have been recently confirmed by the equally instructive experiments of Bischoff, who likewise found, that after the lungs of frogs had been tied and cut out, carbonic acid (to the amount of 0·20 of a French cubic inch, 0·24 of an English cubic inch, in eight hours,) continued to be exhaled by the skin.

Till within the last few years, the theory of respiration was involved in inexplicable difficulties. Blood agitated with atmospheric air was known to yield carbonic acid without the influence of the living organ, becoming at the same time of a bright red colour; it was believed, however, to contain no pre-existing carbonic acid; and yet frogs were found to exhale carbonic acid when no oxygen was respired, and in nearly as large a quantity as in atmospheric air.

Now, however, the problem is satisfactorily solved. The excellent experiments of Professor Magnus have shown that *both kinds of blood contain oxygen, nitrogen, and carbonic acid gas*, that arterial blood contains more oxygen than venous blood, while carbonic acid is in larger quantity in the venous than in the arterial. During respiration carbonic acid is extracted from the blood by the atmospheric air, oxygen being yielded to the blood in its place; a portion of the carbonic acid still remains, however, dissolved in the arterial blood. In the process which is constantly going on between the blood and the texture of the organs in the capillary vessels of the body, the oxygen, which is a vivifying stimulus for the organised substance, disappears in part from the arterial blood, and carbonic acid is formed;

the venous blood therefore contains a larger proportion of carbonic acid, though it retains some of the oxygen. The venous blood reaching the lungs is again deprived of a part of its carbonic acid by the action of the atmospheric air. The interchange of the carbonic acid and oxygen in the lungs is wholly in accordance with the physical laws of the absorption of gases. A fluid impregnated with a particular gas, does not give it out as long as its surface is subjected to the pressure of the same gas; but if it is brought into contact with a different gas, an interchange takes place until the gas with which the fluid is impregnated, and the gaseous atmosphere which presses upon it are equally mixed. This law affords a ready explanation for the exhalation of carbonic acid by frogs in hydrogen and nitrogen in as large quantity as in atmospheric air, as well as for the fact that hydrogen and nitrogen transmitted through blood become impregnated with the carbonic acid which it contains.

The proportion of carbonic acid contained in the blood, is sufficiently large to account for the whole quantity exhaled from the lungs.

Supposing that two ounces of blood are expelled from the heart at each beat, ten pounds must pass through the lungs in a minute; and these ten pounds of blood ought to contain 27·4 cubic inches of carbonic acid,—such being the volume of this gas which Allen and Pepys found to be exhaled from the lungs during a minute's respiration. But admitting that the quantity of carbonic acid really exhaled from the lungs, is less by one half than the experiments of Allen and Pepys would indicate,—and it certainly is less,—and adopting the estimate of Sir H. Davy, who calculated that 15·8 cubic inches is the amount of carbonic acid gas exhaled from the lungs during each minute, still ten pounds of blood ought to contain nearly 16 cubic inches of that gas.

The experiments of Professor Magnus have shown that the blood contains at least one-fifth of its volume of carbonic acid; and since one pound of blood measures about 25 French cubic inches, (one pound avoirdupois of water contains 27·7 English cubic inches,) the same weight of blood about 26·4 English cubic inches, every pound of venous blood ought to contain at least five cubic inches of carbonic acid, and the ten pounds of blood which pass through the lungs in a minute, 50 (60 English) cubic inches, of which it may easily be conceived that 15·8, or even 27·4 cubic inches, may be exhaled in the respiratory process.

A small quantity of nitrogen is absorbed by the blood from the air respired, but does not appear to perform any office in the system, since its proportion is the same in arterial and venous blood.

The object of the respiratory process is evidently, first, the absorption of oxygen into the blood, which conveys that gas as a stimulus to the different organs of the body; and, secondly, the removal from the blood of the carbonic acid which is formed in the capillaries. That the latter is not the main object is clearly shown by the fact of frogs falling into a state of asphyxia when made to respire in hydrogen and nitrogen, although the quantity of carbonic acid which is exhaled in those gases, is not in the slightest degree less than in atmospheric air.(*a*)

(*a*) Are not the views of respiration entertained by the author, as presented in the text, too purely chemical? He admits that carbonic acid is given out from the skin of frogs, as it is known to be from the skin of warm-blooded animals, including man; and, if this be the case, it must be of course under an opposite condition of the capillary circulation from that in the lungs, from which this carbonic acid is given out. In the lungs, carbonic acid is, we are told, exhaled in exchange for oxygen imbibed, and just at the moment of the conversion of dark blood into red. In the skin, carbonic acid is given out in the capillaries at the moment of the conversion of red or arterial into dark or venous blood, but without the imbibition of oxygen, since we know that this latter is less in quantity in the veins than in the arteries,—that is to say, in the present case, it is less after the emission of carbonic acid than it was before. In the lungs, oxygen abounds most in the blood where, in its passage through the pulmonary capillaries, it had just parted with its carbonic acid. Can we qualify by any other term than that of secretion, the emission of carbonic acid from the skin? It takes place in the same condition of the circulation, viz. at the termination of arterial capillaries minutely distributed through a tissue or organ, as all the secretions take place. The chemical view of the respiratory process by which carbonic acid is given out from the pulmonary mucous surface, cannot explain the formation of this gas at the cutaneous surface. But if we should admit the fact of the secretion of carbonic acid from the skin, can we deny it from the lungs,—as far as the circulation in these latter resembles that in the skin, viz. in the passage of blood from the bronchial arteries charged with red blood to the bronchial veins containing dark blood. Müller, in a subsequent chapter, distinctly admits, that, which cannot now indeed, after the experiments of Abernethy, Mackenzie, Anselmino and Collard de Martigny, be denied, viz. the truly secreting process by which cutaneous exhalations and sweat are given out. But neither in that chapter nor on the present occasion, does Müller seem to be aware of the contradiction which these views of cutaneous secretion offer to the purely chemical, I ought rather to say, physical theory of respiration, which he advocates in the text, as all sufficient for an explanation of the actual phenomena. Carbonic acid comes properly under the head of effete matters, the discharge of which, as an excretion, from the system, is brought about by secretion; and if it is eliminated through the skin as a secretion, can we refuse to the lungs a similar glandular office? This indeed is generally admitted for them, except by the pure chemical physiologists, in the case of water, as it unquestionably must be of mucus eliminated from the pulmonary mucous surface. In fine, since both the skin and the lungs give out carbonic acid, water, saline and animal substances, and since both are vital organs, it must be adverse to the laws of induction to explain a part of the elimination (carbonic acid) from one organ, (the lungs,) by purely physical and chemical laws, and precisely an identical part from another organ, (the skin,) agreeably to vital laws or the process of secretion.

Doctor J. Davy, (*Account of some Experiments on the Blood in Connection with the Theory of Respiration*—read before the Royal Society, June 21, 1838,) in illustration of what he believes to be the secreting power of the lungs, mentions the difference of effects in an instance of death by strangulation, and of another by exhaustion of air from the lungs by the air-pump. "A full grown Guinea-pig was the subject of experiment in each. The one killed by strangulation died in about a minute after a cord had been drawn tightly around its neck; the other, placed on the plate of the air-pump, and confined by a receiver just large enough to hold it, lived about five minutes after the exhaustion had been commenced, the pump the whole time having been worked rapidly. The bodies were immediately examined. The heart of the strangled animal was motionless; it was distended with dark blood; twelve measures of the blood, broken up and agitated with twenty more of carbonic acid gas, absorbed eighteen measures, or 150 per cent. The heart of the other Guinea-pig was also distended with blood, but of a less dark hue. Its auricles were feebly acting; the lungs were paler than in the former,

CHAPTER VI.

OF THE RESPIRATORY MOVEMENTS AND THE RESPIRATORY NERVES.

a. The movements of Respiration.

In Mammalia generally, as well as in the human subject, inspiration and expiration are performed by the dilatation and contraction of the cavity of the thorax. As soon as the parietes of the thorax are drawn wider asunder and the thorax dilated, the external air rushes through the trachea and its branches into the air cells, distending them in proportion to the dilatation of the thorax, thus keeping the surface of the lungs accurately in contact with the thoracic parietes in all their movements. This can only take place, however, while the thoracic cavity is closed on all sides, so that the air cannot exert any pressure on the outer surface of the lungs, by which the pressure of the air entering by the trachea, on the inner surface, would be balanced. In cases of penetrating wounds of the thorax, the lungs cannot be fully distended by inspiration; because the counter-pressure of the air entering by the wound balances the pressure of the air on their inner surface; and the lungs in this case remain collapsed, although the thoracic parietes dilate.

Inspiration.—The diaphragm contributes the principal share to

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and more collapsed; ten measures of blood from the heart, broken up and agitated with fifty of carbonic acid, absorbed thirty-seven measures, or 370 per cent.!

"Farther, in illustration of this supposed secreting power of the lungs, I might (continues Dr. Davy) adduce the condition of the blood in disease, and in instances in which I have examined it after death from disease, in the majority of which I have found the blood loaded with carbonic acid, as indicated both by the disengagement of this gas, when the blood was agitated with another gas, and by the comparatively small proportion of carbonic acid which the blood was capable of absorbing. This condition of the blood, in relation to carbonic acid, I believe to be one of great interest and importance, and capable, when further investigated, of throwing light on many obscure parts of pathology, and especially on the immediate cause of death, and that happy absence of pain in dying which is commonly witnessed."

We shall probably make nearer approaches to the truth, by regarding respiration as a function of a mixed kind, or physico-vital, by which water and carbonic acid are exhaled or simply transpired, given out by exosmosis, and oxygen imbibed, passing in by endosmosis; but the rapidity and completeness of these processes will be greatly influenced by the organic properties of the pulmonary mucous tissue itself—just as in gastric digestion, although aliment be an indispensable excitant and support of the function, yet will the extent of change by chymosis depend not only on the amount of aliment ingested but on the vital activity of the gastric mucous surface itself. How far, in addition to the simple modification of the exhalation of carbonic acid and the introduction of oxygen by vitality, there is also a real secretion of the former gas, and absorption of the latter element, is yet to be determined. The distribution of red and black blood through the lungs by the bronchial and pulmonary arteries renders the question of gaseous secretion one of difficult solution, as that of bile has been, owing to a similar double supply of red blood by the hepatic artery, and dark blood by the *quasi* artery or vena portæ.

the dilatation of the chest during inspiration. In the state of relaxation the diaphragm is arched; by contracting it becomes more plane; and by this flattening of its arch the capacity of the thorax is increased, at the same time that the abdominal viscera are pressed upon from above, so as to produce the protrusion or apparent enlargement of the abdomen which is observed during inspiration.

As soon as the diaphragm becomes relaxed, the abdominal viscera recede, and the abdomen again becomes flat. In a natural tranquil inspiration, the dilatation of the chest is effected almost wholly by the diaphragm. The lateral dilatation of the thorax is performed principally by the action of the intercostal muscles, assisted also by the *scaleni*, the *levatores costarum*, the *serratus posticus superior*, and the thoracic muscles generally.

Expiration, when perfectly tranquil, may be the result of the mere collapse or elastic reaction of the parts recovering their natural state after the active dilatations which they have undergone; and, in fact, tranquil respiration seems to consist, not so much in alternate actions of antagonising muscles, as in the periodic action of the muscles of inspiration solely. The elasticity of the lungs themselves, adds Dr. Baly, and the share which they have in producing expiration, have been particularly investigated by Dr. Carson of Liverpool. He made several experiments to determine the force exerted by the lungs by virtue of their elasticity in expelling the air after the act of inspiration had ceased. "In calves, sheep, and large dogs, the resiliency of the lungs was found to be balanced by a column of water varying in height from one foot to a foot and a half; and in rabbits, by a column of water varying in height from six to ten inches." (*Phil. Trans.* 1820.) M. Bazin has recently (*Comptes Rendus, July* 30, 1839,) drawn attention to a capsule of elastic tissue which invests the lungs externally, and sends prolongations inwards, forming the septa between the different pulmonary lobules. In some animals this capsule is very strong and its elasticity very great.

The muscles of expiration may assist by that passive kind of contraction which all muscles possess in addition to their stronger contractile power. However this may be, expiration ensues spontaneously, as soon as inspiration ceases. During a more forcible expiration, the expiratory muscles act more strongly, especially when any irritation is excited in the larynx or lungs, in which case they contract even spasmodically so as to produce cough. The muscles of expiration are the abdominal muscles, which draw down the ribs, and by compressing the abdomen force upwards the viscera against the relaxed diaphragm, and thus diminish the capacity of the thorax from below. These muscles are the *recti*, *obliqui*, and *transversi abdominis*, the *quadratus lumborum*, the *musculus serratus posticus inferior*, the *sacro-lumbalis*, and the *longissimus dorsi*.

Expiration is assisted, first, by the elastic contraction of the air tubes after their distension by the air has ceased; secondly, by contraction of muscular fibres of the air tubes.

Motion of the larynx and fauces.—The glottis is dilated during inspiration, and contracted during expiration. The bronchial tubes are also dilated during inspiration, and contracted during expiration. The air enters and is expelled either by the nose or the mouth. When the air is drawn in and expelled by the nostrils only, the passage through the mouth is closed by the posterior part of the tongue being pressed aganist the palate; if respiration is performed by the mouth, the soft palate is elevated. By approximating the posterior palatine arches (by which means, as Dzondi* has discovered, the communication between the nostrils and lower part of the pharynx is completely closed), and by pressing the root of the tongue against the palate, the mouth, as well as the nostrils, can be completely cut off from the air tubes. This movement is often performed voluntarily, as in holding the breath, and in arresting the passage of unpleasant odours through the nose.†

Muscular contraction of the lungs and air tubes.—The hypothesis of the lungs themselves aiding in the movements of respiration, has from the earliest times been alternately adopted and rejected. Averroes, Riolan, Plater, Sennert, and Bremond (*Mém. de l'Acad. d. Sc.* Par. 1739,) were in favour of it. Th. Bartholin, Diemerhoeck, Mayow, and Haller, (*Elementa Physiol.* t. iii. l. viii. p. 226,) were opposed to it. The former writers observed that, in animals of which the thorax was laid open during life, the lungs did not always collapse, but in some cases continued to move, although the muscles of the thorax could no longer act. More recently, Flormann and Rudolphi have defended this hypothesis. (*Rudolphi, Anat. Physiol. Abhandl.* p. 111.) In a dog which was drowned, the lungs appeared to Flormann to continue to move even after the diaphragm had been divided; and Rudolphi saw the lungs of a dog which had been strangled continue to move even after the sternum had been removed, and the diaphragm and intercostal muscles divided. Such movements have been attributed to shocks communicated from the thoracic parietes; they might also arise from contractions of the heart or of the pulmonary veins. Haller never saw these motions of the lungs; in his experiments the lungs always collapsed perfectly when the thorax was completely opened: the result of my experience is the same, and I conjecture that Flormann and Rudolphi must have been deceived. The farther consideration of this controversy is merely of historical interest; arguments and counter-arguments are repeatedly brought forward, and the inquirer is at last left to the testimony of his own eyes, which in my case is opposed to the hypothesis. Motions were observed by Tiedemann in the respiratory organ of the Holothuria. Treviranus relates that he has seen motion excited in the lungs of the frog by the application of tincture of opium and extract of belladonna. I do not know whether the celebrated author of the "Biologie" attributes much importance to this observation. Frogs fill their lungs with air from their throat, and the air escapes on the glottis and nostrils being opened. If the glottis is opened, the lungs become permanently collapsed, and no contractions can be excited in them. (Consult, on this subject, *Lund, Vivisectionen*, pp. 240—243.)

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* Ueber die Functionen des weichen Gaumens. Halle, 1831. See also Mr. Hilton's observations on the functions of the soft palate and pharynx in No. iii. of the Guy's Hospital reports.

† In birds the air during inspiration enters not merely the lungs, but also the great air cells. Birds have no perfect diaphragm; a few muscular bands arising from the posterior angles of the third, fourth, and fifth rib pass upwards to be attached to a fibrous membrane at the under surface of the lungs. The dilatation of the thorax produces dilatation of large intervisceral cells which communicate with the lungs, and the air is thus drawn into the lungs, through which it must pass to reach these cells. The air is expelled again from these cells, and from the lungs, by the action of the abdominal muscles. In the Chelonian reptiles the ribs are immovable, and the Amphibia—Cœciliæ, Derotremata, Proteida, and Batrachia—have no true ribs; in these animals, consequently, the air is taken in by movements of deglutition. Frogs, having closed the opening of the mouth, dilate the cavity of the mouth and throat so as to draw in the air by the nostrils; then closing the internal apertures of the nostrils by a peculiar mechanism, and the pharynx at the same time, they contract the cavities of the mouth and throat so as to force the air through the glottis into the lungs. The air is expelled partly by the action of the abdominal muscles, and partly by the elasticity of the lungs, the glottis being opened. In the tortoise and turtle the expiration is performed by the contraction of the abdominal muscles between the lower shield or plastron and the posterior extremities. The reptiles which have movable ribs respire by enlarging and diminishing the capacity of their trunk by means of their ribs. For the mechanism of the respiration in fishes, consult Cuvier's Leçons d'Anat. Comp.

The contractile power of the trachea and its branches is, however, less equivocal. It might be supposed that the bronchi contributed to produce the motions observed by Houstoun, Bremond, Flormann, and Rudolphi. It is, however, still matter of doubt whether the muscular fibres of the trachea produce any *rhythmic* motions of contraction and dilatation. The transverse muscular fibres on the posterior surface of the trachea are well known. Muscular fibres are also described as existing on the smaller bronchi. Reisseissen (*De fabrica Pulmon.* Berol. 1822, fol.) has contributed most to draw attention to these fibres. He says that by means of a lens he has recognised muscular fibres on bronchi so small that their cartilaginous plates could no longer be seen.

It is remarkable that there exists at present no direct proof of the contractility of the muscular fibres of the trachea and its branches. All the ducts of glands possess true muscular contractility; they have the power of involuntary motion. (See section on Secretion.) But contractions of the fibres of the trachea have hitherto been observed only by Krimer. (*Untersuchungen über die nächste Ursache des Hustens.* Leipz. 1819.) Wedemeyer applied mechanical stimuli and galvanism to the whole circumference of the trachea in a dog and a hedge-hog, both with and without previous division of the mucous membrane, but could perceive no contractions produced; while bronchi of three-fourths of a line to a line in diameter contracted gradually until their cavity was nearly obliterated. Wedemeyer laid bare the trachea in a living dog, and freed it from cellular tissue for the space of two inches; he then cut out a portion in front, and irritated the posterior wall of the trachea mechanically and by galvanism, but could not produce the slightest contraction. Wedemeyer now opened the thorax quickly, and removed the lungs with their bronchi. He made several sections of the larger bronchi, but could discover no sign of contractility in them. On applying galvanism, however, to the smaller branches of about one line in diameter, he thought that he saw them undergo a distinct constriction, but it took place very slowly. The last phenomenon had been before observed by Varnier. It is probable, therefore, that the bronchial tubes and trachea do not contract and dilate rhythmically during the movements of respiration. Had they this power, it would be quite an isolated fact; for although the hepatic duct presents rhythmic contractions, they are quite independent of volition; while, if the bronchi contracted and dilated synchronously with the other respiratory movements, their action, like that of the other parts engaged in respiration, must also be subject to the will, and it is highly improbable that the branches of the efferent tube of an internal viscus would be thus under the influence of the will. It is possible that the fibres of bronchi may possess a contractile power which is constantly in action, and which may effect the contraction of the tubes on the cessation of the act of inspiration: but mere elasticity would be sufficient for this purpose.

In man the dilatation of the bronchi during inspiration, and the shortening of the trachea during inspiration, and its lengthening during expiration, which some physiologists have observed, seem to be merely the mechanical results of the dilatation and contraction of the thorax; the larynx itself descends a little during violent inspiration, and ascends again during expiration.*

b. Of the influence of the nerves on the function of respiration.

The source of the nervous influence on which the different respiratory movements depend, is one and the same, although the nerves implicated in these movements are various.

The respiratory movements are: 1st. Movements in the face, which, however, are but seldom exerted in rhythmic order; such are the elevation and depression of the alæ of the nose, and the straining of several muscles of the face during respiration. These movements are observed in violent involuntary acts of respiration, and even in a state of great debility; they are under the influence of the *portio dura*, or facial nerve, which Sir C. Bell calls the respiratory nerve of the face. 2d. Dilatation of the glottis during inspiration, and its contraction during expiration. This motion is wholly subject to the action of the two laryngeal branches of the nervus vagus, the *nervus laryngeus superior et n. l. inferior seu recurrens.* 3d. Lateral dilatation of the thorax during inspiration, effected through the agency of the spinal nerves, the respiratory external nerve of Bell, and the accessory nerve of Willis, which supplies the trapezius with nervous influence for the elevation of the shoulder. 4th. Contraction of the diaphragm in the act of inspiration,—dependent on the phrenic nerve. 5th, and lastly. Contraction of the abdominal muscles in expiration,—through the influence of spinal nerves. The respiratory nerves, then, are the portio dura of the seventh, the nervus vagus, accessory nerve, and many spinal nerves distributed to the muscles of the trunk.

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* Birds have certainly the power of shortening their trachea by means of particular muscles, the musculi sterno-tracheales and ypsilo-tracheales; and in many birds there are several muscles at the inferior larynx at the division of the trachea, for the purpose of producing their song. It is a very interesting fact, that the former muscles are supplied with a special nerve, a second descending branch of the ninth nerve, which descends nearly as far as the inferior larynx, and (in the turkey) supplies the sterno and ypsilo-tracheal muscles; while the recurrent nerve, destined chiefly for the œsophagus, gives a proportionally short branch to the trachea. I have hitherto had no opportunity of ascertaining the correctness of the assertion of Desmoulin, that the inferior larynx is supplied from the inferior cervical nerves.

Each of these nerves has its own sphere of action, and one of them may be deprived of its function without the others being affected. The division of any one of them puts a stop to that set of movements which depend upon its influence; but destruction of the medulla oblongata annihilates all the respiratory movements, and the action of all those nerves which arise from the spinal cord. The medulla oblongata is the source from which the nervous influence for the respiratory motions is derived; and the spinal cord is, as it were, the trunk of the nerves which arise from it. If the spinal cord is divided above the point where the dorsal nerves are given off, the motions of the ribs and abdominal muscles are paralysed, while the other respiratory movements continue. If the spinal cord is cut through above the origin of the phrenic nerves, the diaphragm is paralysed, while the nerves given off from the medulla oblongata itself still continue to exert their function. The nerves coming off from the spinal cord below the lesion, are still capable of exciting motions when irritated singly, but they can no longer receive the motor influence from the common source of all the simultaneous, voluntary and involuntary, movements of respiration. Injury of the medulla oblongata puts an end immediately to all the respiratory motions,—as well to those dependent on the nervus vagus as to those of the trunk, which are dependent on spinal nerves.

Legallois pointed out this connection between the medulla oblongata and respiration; he proved that no other parts of the brain are the source of the respiratory movements, and that the brain of an animal may be removed piece by piece from before backwards, until, on wounding the medulla oblongata at a point corresponding to the origin of the vagus nerve, all respiratory movements at once cease. Hence the medulla oblongata is the most mortal part of the body; lesion of it is, at least, followed by more dangerous consequences than that of any other part of the nervous system.

Lesion of the nervus vagus in the neck paralyses the branches arising below the injury, and therefore the nervus recurrens. The consequences are loss of voice, and difficulty in dilating the rima glottidis. The voice returns, however, in a few days, because the muscles of the larynx are supplied in common by the superior and inferior laryngeal nerves. If the superior and inferior laryngeal nerves of both sides are divided, the larynx is quite paralysed. Magendie's assertion, that the nervus laryngeus inferior supplies only those muscles which dilate the glottis, and the nervus laryngeus superior those which contract it, is not confirmed by the investigations of Schlemm and others; both nerves are distributed to both sets of muscles. If there is any difference in the functions of the two nerves, it can arise merely from the recurrent nerve being in its remarkable course connected with the sympathetic nerve and cardiac plexus, and thus having, in addition to the voluntary motor fibres of the vagus, also fibres from the sympathetic system. It is not known whether the recurrent nerve gives the power of voluntary contraction to the muscles of the larynx. Other deep branches of the vagus which have many connections with the sympathetic nerve, such as the œsophageal and gastric branches, are no longer capable of exciting voluntary motion.

Sir C. Bell's views regarding the respiratory nerves may very properly be explained here.—The aspect of a man in a state of excited action is sufficient to prove that the movements connected with the function of respiration extend over almost the whole body; they are observable in the abdomen, chest, neck, and face. The respiratory nerves belong to a two-fold system. To the system of spinal nerves, with two roots,—a sensitive posterior root provided with a ganglion, and a motor or anterior which has no ganglion,—comprehending all the spinal nerves and the *nervus trigeminus* or fifth pair,—belong those respiratory nerves arising from the spinal cord which serve for the motion of the thoracic and abdominal muscles. The second system of nerves which furnishes respiratory nerves, consists of those which arise by but one kind of root; the respiratory nerves of this system are the facial nerve and the vagus and the accessory nerve of Willis. Bell supposes that a special set of fibres in the medulla oblongata and spinal cord is the source of the influence which gives rise to the simultaneous and harmonious action of the respiratory nerves of both kinds. All the respiratory nerves serve also as the principal nervous agents in the expression of the passions. A great portion of the spinal nerves concur to produce the movements of respiration; but Bell distinguishes the following as the special respiratory nerves for particular regions:—

1st. The *nervus vagus*,—the respiratory nerve of the larynx.

2d. *Nervus facialis* (*portio-dura*),—respiratory nerve of the face. The respiratory action of this nerve is more evident in proportion as respiration is more laboured; for instance, during great muscular exertion, and in feeble debilitated persons. The elevation and depression of the alæ of the nose and the straining of the muscles of the face, in this laboured respiration, are dependent on the influence of the facial nerve. If this nerve is divided, the sympathy of the countenance with the respiratory organs, and the expression of the passions, are lost. In brutes, the development of the facial nerve is proportionate to the degree in which the passions are expressed by movements of their face.

3d. The superior respiratory nerve of the trunk,—*nervus accessorius Willisii*,—is distinguished by its remarkable course. It arises by a simple root between the double roots of the spinal nerves at the upper part of the spinal cord; ascends, receiving other fibres[1] from the medulla oblongata, into the cavity of the cranium; and issues from it again as a single nervous cord. It gives a portion of its fibres to the vagus, and directs the action of the trapezius when it co-operates in the respiratory movements, by elevating the shoulder so as to free the thorax from its weight. If the *nervus accessorius* is divided in a living animal, the action of the trapezius in respiration ceases; but it still retains its power of voluntary motion by virtue of the branches of spinal nerves distributed to it.

4th. The great internal respiratory nerve,—*nervus phrenicus*, or diaphragmatic nerve.

To the posterior thoracic nerve Bell attaches too much importance.

The source whence all the nerves above enumerated derive their nervous influence is, as we have seen, the medulla oblongata. Lesion of that part of the nervous centres puts a stop to the respiratory movements, while, according to Bell, if the spinal marrow is divided at the fifth cervical vertebra, the phrenic nerve not being implicated in the injury, respiration is still carried on by the agency of the phrenic, accessory and external respiratory nerves; expiration being performed by the mere elasticity of the thoracic and abdominal parietes; and a new-born child, according to Bell, continues to breathe when nearly the whole brain is destroyed, if the medulla oblongata is uninjured.*

Sympathetic affections of the respiratory muscles.—I have already mentioned that the whole system of nerves engaged in the respiratory movements serve likewise for the expression of the passions. They are also affected partially, or all simultaneously, in many other cases. Nervous affections, which take the form of asthma, afford an example of convulsive action of the whole system of respiratory nerves. But a fact not noticed by Bell, which nevertheless appears to me to throw such light on many phenomena, is, that local irritation of any part provided with mucous membrane is adequate to excite the respiratory system of nerves to morbid action, so as to produce convulsive motions. Irritation of the mucous membrane of the nose produces sneezing; irritation in the pharynx, œsophagus, stomach, or intestines, excites the concurrence of the respiratory movements to produce vomiting; violent irritation in the rectum, bladder, or uterus, gives rise to a concurrent action of the respiratory muscles so as to effect the involuntary expulsion of the fæces, urine, or fœtus. Irritation of the mucous membrane of the larynx, trachea, or lungs, or even itching from irritation in the Eustachian tube, excites coughing.

All these acts,—coughing, vomiting, spasmodic involuntary expulsion of the fæces, and involuntary discharge of urine, are effected with the aid of the respiratory movements. The first action of the local irritation affecting the inner coats of the viscera, is upon the branches of the sympathetic nerve distributed to them; and in the stomach, œsophagus, pharynx, larynx, and lungs, upon the branches the nervus vagus also; in the nostrils upon the branches of the *rvus trigeminus* or fifth pair. From these nerves the irritation is ansmitted to the medulla oblongata and the spinal cord, from which s derived the nervous influence for the groups of respiratory muscles which perform the acts of vomiting, coughing, sneezing, &c. Irritation of the nasal branches of the fifth nerve produces sneezing, even when the irritation affects them indirectly; for instance, when the stimulus of the sun's light acts first on the optic nerve, and through the medium of it on the brain, a secondary excitement is sometimes communicated to the nasal, and at the same time to the respiratory nerves. Like many other persons, I sneeze whenever the bright light of the sun falls on my eyes. Irritation of the vagus in the larynx, trachea, or lungs, excites coughing; irritation of the pharyngeal branch of the nervus vagus, and of the glosso-pharyngeal nerve, in the pharynx, or of the vagus in the stomach, excites vomiting. We will now consider, separately, each of these groups of respiratory movements.

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* Sir C. Bell on the Nervous System.—Phys. Pathol. Untersuch. des Nervensystems, übersetz von M. H. Romberg, Berlin, 1832, pp. 126-338. See also Müller's Archiv. 1834, 168.

Each individual respiratory movement can be performed singly,—sometimes, however, several are combined,—giving rise to complicated movements which are not observed in ordinary respiration.

Contraction of the diaphragm takes place at the same time with the movements of expiration, either voluntarily or involuntarily, in the act of forcible expulsion of a substance from some part of the abdominal cavity; voluntarily in *the discharge of fæces and urine;* involuntarily in *vomiting*, in *labour*, and in the *involuntary discharge of fæces or urine* after they have been too long retained. The pharynx, stomach, rectum, bladder, and uterus have all such a connection with the cerebral and spinal nerves, that irritation of any one of the parts mentioned, excites contraction, not merely of them, but also of the abdominal muscles and diaphragm, so as to cause the expulsion of the irritating body either upwards or downwards. This results from the reflection of the irritation from the branches of the nervus vagus, in the pharynx and stomach, on the brain, and from the sympathetic nerves of the stomach upon the sympathetic system, and upon the brain and spinal marrow; and in the instances of the rectum, uterus, and bladder, from the irritation of the nerves of those parts, which are derived partly from the sympathetic system and partly from the sacral nerves, being communicated to the spinal cord. In all these movements, of which the object is the expulsion of a body upwards or downwards, the glottis is closed for a time.

I have observed a circumstance which is very instructive with reference to the mode of production of vomiting. If the abdomen of a rabbit is opened, and the left splanchnic nerve laid bare on the inner side of the suprarenal capsules, and irritated with a needle, a contraction of the abdominal muscles often takes place. In the dog I have not found the same to be the case.

The act of *coughing* arises from the irritation of the nervus vagus in the larynx, trachea, and lungs being communicated to the medulla oblongata. The medulla oblongata then excites to action the muscles which produce contraction of the glottis, and at the same time gives rise to spasmodic actions of the expiratory muscles of the thorax and abdomen; during each act of expiration the glottis is partly opened, and a loud noise produced. The diaphragm has nothing to do with the act of coughing, except that sometimes, before coughing, a deeper inspiration is taken. Krimer (*Untersuchungen über den Husten*) and Brachet state that after the nervus vagus has been divided on both sides, coughing cannot be again excited in an animal by irritation, however violent, of the inner surface of the trachea.* While division of the sympathetic nerve is said by Krimer not to have the same effect.

We have the power of cutting off the entrance into the larynx from the nose and mouth, not merely by closing the glottis, but also, as was discovered by Dzondi, by a muscular action in the fauces themselves. It consists in bringing the posterior arches of the palate in contact from opposite sides, and in pressing the posterior part of the tongue against the inclined plane thus formed. This movement always precedes *sneezing*, which is a sudden and violent contraction of the muscles of expiration, the air passages having been previously closed at the fauces. At the moment of the violent expiration, the passage by the mouth and the nasal canal are suddenly opened simultaneously, or the nasal canal alone. The diaphragm, which so many ancient and modern authors, misled by a popular error, believed to contribute to the act of sneezing, has in reality nothing to do with it. The diaphragm is not an expiratory muscle; it only acts in producing the deep inspiration which precedes the sneezing. Extensive sympathies, which appear to be quite unnecessary, have been imagined to explain the act of sneezing, from the false notion that it is produced by the diaphragm; the irritation of the nasal nerves was supposed to be communicated to the deep branch of the vidian and to the sympathetic; and thence to the cervical nerves and nervus phrenicus. Even Arnold still speaks of such a chain of sympathy. Since the expiratory muscles, and not the diaphragm, effect the act of sneezing, the fauces and posterior nares being first closed, the most simple view to be taken of the matter is, to consider the medulla oblongata itself as the medium of communication between the nasal branches of the fifth nerve and the expiratory muscles and muscles of the soft palate, just as the sympathetic motions of the iris are excited by the stimulus of light, through the intervention of the brain.

The sympathy of a great part of the nervous system with local irritations through the medium of the brain and spinal marrow are very well illustrated by the symptoms observed in an animal under the influence of a narcotic poison, when a slight touch of the skin produces general tetanic spasms.

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* In some experiments performed by Dr. J. Reid also, the sensibility of the mucous membrane of the trachea and bronchi was much blunted after the division of the vagi. But in four dogs which lived beyond the fourth day after the division of the vagi—and in three of which the recurrent nerves were also divided,—frequent cough, or at least forcible expirations, which could not be distinguished from a cough, were observed. This might have been dependent on irritation of the upper part of the cut nerves; but when examined after death, they presented no marks of high inflammation.—(Dr. Reid, Edin. Med. and Surg. Journal, April, 1839, also *Am. Edit. Reid on the Nerves*.)

Yawning consists of a deep and slow inspiration, and expiration with simultaneous action of the respiratory muscles of the face. The mouth is at the same time opened wide; a movement which, like those of the facial muscles, is also under the influence of the facial nerve, being effected by means of the digastricus. Yawning occurs generally after fatigue, and is especially frequent and easily excited in persons of irritable and debilitated nervous system; also during the state of drowsiness, and at the commencement of fever. The supposition that it arises from some obstruction in the pulmonary circulation, appears to me to be quite incorrect. *Laughing* and *crying* are also attended with affections of the respiratory nerves of the face and trunk.

Hiccough is really an affection of the diaphragm,—an abrupt inspiration performed by the diaphragm alone, which sometimes contracts while the glottis is closed. It arises most frequently from some pressure on the pharynx or œsophagus, in consequence of swallowing too large morsels, or of swallowing too quickly in succession, but is also a frequent symptom of affections of the nervous system. Krimer asserts that hiccough can be induced in brutes by irritating and compressing the cardiac orifice of the stomach.

All the respiratory movements are performed involuntarily, and are nevertheless to a certain extent subject to the will; they are carried on in a constant and regular succession during sleep, and at other times, without our consciousness; they frequently consist merely of periodic inspirations, in the intervals of which the parts return to their former state by virtue of their elasticity; frequently also there are alternate muscular actions of inspiration and expiration. If the structure of the lungs is in part destroyed or loaded with blood, a much less quantity of the fluid can be aerated in a given time, and the respiratory movements are then proportionally quicker. The movements of respiration are so far subject to the will, that we can, though only in a certain degree, regulate the commencement of each inspiration,—can shorten, prolong, or delay it,—and can limit the respiratory movements to single groups of the respiratory muscles; thus, for example, we can inspire with the diaphragm only, or with the ribs only, or with both at the same time. This voluntary influence is exerted in the same manner as in the case of almost all motions which are dependent on the function of the cerebral and spinal nerves; and the power of exerting it is preserved as long as the corresponding nerves are still in connection with the brain and spinal cord.

The *regular succession of the involuntary respiratory movements* is very remarkable and difficult of explanation. We have seen that the continuance of the respiratory movements is dependent on the integrity of the medulla oblongata. How that part of the nervous centres acts, in determining their rhythm, and the cause of the first respiration in the new-born child, will be considered in a subsequent part of this volume, under the head of the automatic movements.

Effects of division of the nervi vagi.—A consideration of all the different results obtained by the various observers, (*Legallois*, *Dupuytren*, *Blainville*, *Dumas*, *Emmert*, *V. Pommer*, *Arnemann*, *Provençal* and *Mayer*,) leads to the inference that death, after tying or dividing the nervus vagus, arises from the concurrence of different circumstances, which at last produce suffocation. They are the following:—1. Incomplete paralysis of the muscles of the glottis. 2. Exudations in the lungs. 3. Change in the chemical process going on in the lungs. 4. Coagulation of the blood in the vessels, as observed by Mayer.

It appears, adds Dr. Baly, from Dr. J. Reid's observations, (*loc. citat.*) that section of the vagi nerves is not always fatal by producing morbid changes in the lungs; in two out of seventeen dogs experimented upon, the lungs were found perfectly healthy. One of these dogs died after the completion of the eighth day, apparently from inanition; the other was killed after the twelfth day, when apparently in perfect health. Dr. Reid shows that the effusion into the bronchi is not the cause of the laboured respiration in animals of which the vagi nerves have been divided, but its indirect effect. In several experiments it was absent, or existed only in a trifling degree. Congestion of the blood-vessels seemed to be the first stage of the morbid changes in the lungs. The diminished frequency of the respiration is regarded by Dr. Reid as the cause of this congestion. In opposition to the observations of Magendie, Wilson Philip, and Swan, Dr. Reid states that lesion of one pneumogastric nerve does not induce disease of the corresponding lung; in seventeen animals, in which he had removed a portion of one vagus, and which were allowed to live from twenty-four hours to six months, he could detect no morbid change in the lungs, which he could attribute to the operation. This renders it very improbable that section of both vagi affects the lungs, by suspending some direct influence of those nerves upon them, and rather favours Dr. Reid's opinion as to the mode in which the operation affects those organs, since lesion of one vagus diminishes very slightly the frequency of the respirations.

SECTION I.

OF DIGESTION, CHYLIFICATION, AND THE EXCRETION OF THE DECOMPOSED EFFETE MATTERS.

CHAPTER I.

Of Digestion in General.

THE *food of animals* consists of animal and vegetable substances. Some animals live solely on the former class of substances, others on the latter; others, again, amongst which is man, have a mixed diet, consisting of both animal and vegetable matters. Man is supported as well by food constituted wholly of animal substances as by that which is formed entirely of vegetable matters; and the structure of his teeth, as well as experience, seems to point out that he is destined for a mixed kind of aliment.

Both the vegetable and animal articles of diet contain the more common salts, which, being essential components of the animal system, may in a certain point of view be regarded as nutriment. But no animal can subsist on mineral substances alone; though from necessity, or from prejudice, for the purpose of filling the stomach, earth, either alone or mixed with organic matters, is sometimes swallowed by human beings,—for instance, by the Ottomaks and Guamos in Oronoco, and by the inhabitants of New Caledonia. Vauquelin could detect no nutritious matter in the steatite which is eaten by the inhabitants of New Caledonia.* The earth, which, on account of famine, was, in the year 1832, in the parish of Degernä, on the borders of Lapland, mixed with flour and the bark of trees, and baked so as to form a kind of bread, consisted of siliceous earth mixed with organic particles. (*Poggendorf's Ann.* B. xxix. p. 261.) This mineral flour was found by Retzius to consist of the fossil remains of nineteen different forms of infusoria.

All substances from the animal and vegetable kingdoms appear to afford nutriment, provided that they are easily soluble in the animal fluids, contain no combination of elements too unlike that of the animal matters of the being which they ought to nourish, possess no remarkable chemical properties, and have no tendency to enter into binary combinations at the expense of the organic components of the living body. Substances which have such a tendency, which are of heterogeneous composition, or have peculiar chemical properties, are either medicinal substances, or, in a relative sense, poisons. I am much inclined to believe that even the peculiar effects of the narcotic poisons which produce no evident material change in the system, and do not essentially excite inflammation, arise from the heterogeneous and peculiar chemical substances which they contain causing decomposition and the formation of binary compounds in the animal matter of the body. This opinion appears to me to be rendered probable by the fact that the substances to which we allude contain vegetable alkaloids, and that, according to the observation of Fontana, the most active narcotic poisons—the poison of the viper and the ticunas,—exert a chemical action on animal substances, the effect of which has been particularly observed in the blood.* The term "poison" is to be taken in quite a relative sense. The poison of serpents when introduced into the blood produces decomposition of the animal fluids; but, when taken into the stomach, it is rendered innocuous, being decomposed, as it would seem, in the alimentary canal. The poison of the viper exerts its noxious influence very slowly likewise, when applied to wounds in the lower vertebrata, particularly in the amphibia—as frogs,—and in the blind-worm; to serpents, it would appear to be innocuous. Most narcotic poisons, however, are, in large doses, poisonous even to the lower animals. Prussic acid is as destructive to leeches as to the human subject; opium and nux vomica appear to be poisonous to all animals, with the exception of the bird, *Buceros rhinoceros*, which is said to feed on the nuts of the strychnos.

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* See Humboldt's Reise in den Equinoct. Gegend. iv. p. 557. Travels in the Equinoctial Regions of the New Continent, translated.—Rudolphi's Physiol. ii. 18.

The most simple nutritive substances from the vegetable kingdom are,

1. The acid juices of many plants and fruits.
2. Starch (amylum)—in the seeds of the grasses and leguminous plants, in the tubera of the potato, in sago, and in lichen Islandicus.
3. Vegetable mucilage—in roots and seeds, and in the form of the different gums. It differs from animal mucus in being soluble in water.
4. Sugar—in the juices of many plants, and of their fruits.
5. Fatty, or fixed vegetable oils—in seeds and some tuberous roots.
6. Vegetable albumen—in the milky juices of vegetables, in the milk of the milk-tree, brosimum galactodendron, (*Don in Ed. N. Phil. Journ.* 1829, Oct. Dec.) and in seeds which yield emulsions by trituration.
7. Gluten—generally combined with albumen in the different kinds of grain and other seeds, also in sweet fruits.
8. Fungin—in the fungi.

Many other substances,—the spirituous and aromatic substances, for example—merely stimulate the digestive organs, and do not afford nourishment. The woody fibre, the investments of seeds, most resins, colouring and extractive matters, hairs, feathers, horn, claws, scales, the external skeleton of insects, and all horny substances generally, are indigestible.

The principal nutritive principles derived from the animal kingdom are,

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* See page 143. For an account of the vegetable poisons, consult Christison and others on Toxicology; on animal poisons, see Rudolphi, loc. citat.

1. Gelatin—in the tendons, bones, cartilages, the skin, the cellular tissue, and especially in very young animals.

2. Albumen—principally in the ova, in the brain and nerves, in the blood, &c.

3. Fibrin—in muscular substance, and in the blood.

4. Animal oil and fat. (For an account of the properties of these principles, see Book I, Sect. 1, p. 97—105.)

5. Casein—in milk, with animal fat (butter), and in cheese.*

Nutritive principle of food.—The end and object of digestion are, *first*, the solution of the food, since nothing can be taken up by the absorbent vessels which is not in solution; and, *secondly*, the reduction of the different ingredients of the food above enumerated into the most simple material of the animal processes, namely, albumen, which is found to be contained in the fluid resulting from the digestion of the food, partly in the state of solution, and partly in globules. To effect these changes, something more than mechanical division is required; chemical influences,—digestive fluids,—are essential. Those substances, then, are most easy of digestion, and most nutritious, which are most easily soluble and most readily converted into albumen, or which themselves contain albumen; and hence we see that the yolk of the egg, being a concentrated solution of albumen (with oil), forms for the embryo a nutriment which is assimilated immediately without any previous digestion. Everything, on the other hand, is indigestible, which, either like woody fibre and the skin of fruits, can afford no nutriment, on account of its insoluble nature, or itself exerts a chemical action so as to call into play the tendency of the elements of the organic matter to form binary compounds, a tendency which had been previously counterbalanced by the organic force. A distinction must be made also between substances easy of digestion and nutritious substances. A substance may, by reason of its solubility, be in that sense easy of digestion, and yet afford little nourishment, its composition being such that it is with difficulty converted into albumen. Other substances, which, when once dissolved, are very nutritious, may, on the other hand, be difficult of solution, and thus indigestible for weak digestive powers. Good food, therefore, must not only be easy of solution, but also nutritious in its nature. The farther a substance is removed in its composition from that of albumen the less nutritious will it be, and the greater expenditure of the digestive powers is required for its conversion into chyle.

If digestion consisted merely in the solution of the food, and if all articles of diet contained a certain quantity of one and the same nutriment, for which no further chemical change was required, the quality of any article of food might be determined by ascertaining its degree of solubility, the quantity of nutriment which it contained, and the degree of difficulty attending the extraction of this nutriment from the other ingredients of the substance. The dogma of Hippocrates that there are different kinds of food, and but one kind of nutriment (*alimentum*), is founded on this incorrect conception of the nature of nutriment. Some of the substances which are taken as food, and which must be converted into albumen,—for instance, vegetable substances,—contain no albumen before they are digested. "Alimentum," in the sense in which the term is used by Hippocrates, is therefore the product of digestion; to afford which, those substances that differ in their composition from albumen require to undergo in the stomach a chemical change.

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* A full account of all the substances used as food, is contained in the third volume of Tiedemann's Physiologie. Darmstadt, 1836. See also on this subject, as well as on the dietetic regimen of the people in different countries, *Regimen and Longevity*, by John Bell, M. D. Philadelphia, 1842.

Azotized and unazotized aliments.—M. Magendie has pointed out* an important distinction which may be made in the alimentary substances, between those which contain nitrogen and those in which it constitutes little or no part.

The substances which contain little or no nitrogen are the saccharine and acid fruits, oils, fats, butter, mucilaginous vegetables, refined sugar, starch, gum, vegetable mucus, and vegetable gelatin. The different kinds of corn, rice, and potatoes, are aliments of the same kind. The azotized aliments are vegetable albumen, gluten, fungin, and some matters met with in different plants, which resemble osmazome: these azotized vegetable principles are met with principally in the seeds of the grasses, and in the stems and leaves of the grasses and herbs, the seeds of leguminous plants—lentils, peas, and beans; and almonds and nuts also contain them. Of the animal substances which contain nitrogen the chief are gelatin, albumen, fibrin, and casein. Most animal substances, with the exception of fat, contain more or less nitrogen. Some writers have supposed that respiration is the source whence the nitrogen of the animal body is derived, while others have imagined that it is generated from other elements. The instance of the herbivorous animals which feed on substances that contain little or no nitrogen, and that of the negroes, who live for a long time on a diet consisting entirely of sugar, have been adduced in support of these opinions. M. Magendie, however, observes that almost all the vegetables which afford nourishment to animals and man contain more or less nitrogen, that this element enters in pretty large quantity into the composition of impure sugar, and lastly, that the nations which feed on rice, maize, or potatoes, take also milk or cheese.

Very valuable experiments have been instituted by M. Magendie to determine the degree of nutritive property possessed by substances which contain no nitrogen,—for example, by food consisting wholly of sugar and distilled water. The experiments were performed on dogs. During the first seven or eight days the animals were brisk and active, and took their food and drink as usual; but in the course of the second week they began to get thin, although their appetite continued good, and they took daily between six and eight ounces of sugar. The emaciation increased during the third week, and they became feeble, and lost their activity and appetite. At the same time an ulcer appeared on each cornea, followed by an escape of the humours; this took place in repeated experiments. The animals still continued to eat three or four ounces of sugar daily; but nevertheless became at length so feeble as to be incapable of motion, and died on a day varying from the 31st to the 34th. (And it must be recollected that dogs will live the same length of time without any food at all.) After death the muscles were found very much wasted, the stomach and intestines much contracted, and the gall-bladder and urinary bladder distended. The urine was analysed by Chevreul, and found to be alkaline, as in herbivorous animals, and to contain no uric acid or phosphates. The bile contained abundance of picromel, which also exists in large proportion in the bile of herbivora, but which has been recently found to be likewise present in the bile of carnivorous animals. The fæces contained but little nitrogen, although it generally forms a large part in their composition. To ascertain whether these effects are peculiar to a sugar diet, or result from the want of nitrogen, Magendie kept dogs on olive-oil and water. All the phenomena produced were the same, except that no ulceration of the cornea took place. The same was the result when dogs were fed on gum alone, which is a very nutritious substance if taken mixed with other aliments, but which contains no nitrogen. With butter the effects were the same, and the dog died on the thirty-sixth day, although meat was given him on the thirty-second day; one eye ulcerated: and the urine and bile were found in him, as well as in the dogs fed with gum and oil, to be of the same composition as in those fed on sugar. By other experiments, Magendie ascertained that chyme and chyle are formed from sugar, oil, or gum; and that consequently it is not from want of being digested that these substances do not nourish the animals. In addition to the experiments here detailed, the fact may be adduced that in Denmark a diet of bread and water for four weeks is considered equivalent to the punishment of death; and that Dr. Stark died, in consequence of experiments which he instituted on himself, to determine the effects of long-continued sugar diet: after taking such food for some months, he became extremely feeble and swollen, and red spots appeared on his face, and threatened to break out into ulcers.

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* Physiol. edit. 2, t. ii. p. 426. Milligan's Translation, 4th edit. p. 223.

Magendie's experiments have thrown some light on the causes and mode of treatment of gout, and calculous disorders. The subjects of these diseases are generally persons who live well, and eat largely of animal food: while most urinary calculi, gravelly deposits, the gouty concretions, and the perspiration of gouty persons, contain abundance of lithic acid, a substance into the composition of which nitrogen enters in large proportion. By diminishing the proportion of azotized substances in the food, the gout and gravelly deposits in the urine may be prevented.

Tiedemann and Gmelin have confirmed Magendie's experiments. They fed different geese, one with sugar and water, another with gum and water, and a third with starch and water. All gradually lost weight. The one fed with gum died on the sixteenth day; that fed with sugar on the twenty-second; the third, which was fed with starch, on the twenty-fourth, and another on the twenty-seventh day; having lost during these periods from one-sixth to one half of their weight. But a goose which was fed with boiled white of egg cut into small pieces, although it maintained its appetite, and the food contained nitrogen, also died on the forty-sixth day, after having lost nearly one half of its weight. These experiments of Tiedemann and Gmelin, like those of Magendie above detailed, would be very conclusive if the same animals had been fed alternately on different substances that contained no nitrogen; for the experiments of Magendie, which follow, show that animals are frequently not able to support a diet consisting invariably of one and the same substance, though it contain azote. (See *Londe, Froriep's Notiz.* Bd. xiii. No. 10.)

Necessity of variety in diet.—Magendie's further experiments on the nutritious property of different substances afforded the following facts:—1. A dog fed on white bread, wheat and water, did not live more than fifty days. 2. Another dog, on the contrary, which was kept on brown soldier's bread, did not suffer. 3. Rabbits and Guinea-pigs fed on any one of the following substances,—wheat, oats, barley, cabbage, or carrots,—died with all the signs of inanition in fifteen days; while, if the same substances were given simultaneously, or in succession, the animals suffered no ill effect. 4. An ass fed on dry rice, and afterwards on boiled rice, lived only fifteen days. A cock, on the contrary, was fed with boiled rice for several months with no ill consequence. 5. Dogs fed with cheese alone, or with hard eggs, lived for a long time, but they became feeble and thin, and lost their hair. 6. Rodent animals will live a very long time on muscular substance. 7. After an animal has been fed for a long period on one kind of aliment, which, if continued, would not alone support life, he will not be saved by his customary food being given to him: he will eat eagerly, but he will die as soon as if he had continued to be restricted to the one article of food which was first given. The conclusion to be deduced from the above facts is, that variety of the kinds of aliment is an important circumstance to be attended to in the preservation of health. The statement of M. Magendie, that for the nutrition of animals variety of diet is necessary, and that restriction to one kind of food induces emaciation and death, has been fully confirmed by a comparative experiment instituted on three rabbits by M. E. Burdach. (*Froriep's Not.* Oct. 1839, p. 43.)

Dr. Prout (*on the Nature and Treatment of Stomach and Urinary Diseases,*) reduces all the articles of nourishment, among the higher animals, to four great classes or groups: 1, the *aqueous;* 2, the *saccharine,* comprehending sugar, starch, gum, &c.; 3, the *oily,* including oils and fats; and 4, the *albuminous,*—the last the proximate principle of animals, and a modification of which is vegetable gluten. After a short account of each of these classes, he makes the following summary of the subject:—

"Such are the four great alimentary principles, by which all the higher animals are nourished, and of which their bodies are essentially constituted; and if we regard carbon as the elementary principle by which, *cæteris paribus*, the nutritive powers of three of the alimentary principles are measured or represented, (which, in a certain point of view, may be considered to be the case,) we shall find them to stand in the order in which they have been above described; that is, the saccharine principles contain on an average from forty to fifty per cent. of carbon: the albuminous (including azote) from fifty to seventy-five per cent.; and the oleaginous about eighty per cent. of this principle. Of these principles it has already been remarked, that without any alteration in their essential composition, they are capable of assuming an infinite variety of modified forms; many of which are so peculiar, that from their sensible properties it is very difficult to recognise their identity. Moreover, these staminal principles, in all their forms, are capable of readily passing into, and of combining with, each other; at least the organic agents, as we shall see hereafter, have the power of effecting such changes. Further, these staminal principles are all susceptible of transmutation into new principles according to certain laws; thus the saccharine principle is readily convertible into oxalic acid; or, under other circumstances, into the modification of the oleaginous principle, alcohol. Though an endless variety of these modifications of the staminal principles exist in different organised beings, still the proportion they bear to the staminal principles is very limited; and they are either confined to glandular secretions; or are excrementitious; or extravascular; that is, these modifications and combinations form no part of the living animal, though they are often attached to it; as in the case of the shells, &c., of the molluscous tribes. They also exist in many excreted products.

"From this essential identity between the alimentary matters by which animals are nourished, and the composition of their own bodies, it not only follows that in the more perfect animals all the antecedent labour of preparing these compounds *de novo*, is avoided; but that a diet, to be complete, must contain more or less of all the four staminal principles. Such at least must be the diet of the higher classes of animals, and especially of men. It cannot indeed be doubted that many animals, on an emergency, have the power of forming a chyle from one or two of these classes of aliments; but that the higher animals can be so nourished for an unlimited time is exceedingly improbable. Nay, if we judge according to what is known from universal observation, as well as from experiments which have been actually made by physiologists regarding food; we are led to the directly opposite conclusion, namely, that the more perfect animals could not exist on one class of aliments; but that a mixture of three at least, if not of all the four staminal principles, is necessary to form an alimentary compound well adapted to their use.

"This view of the nature of aliments is singularly illustrated and maintained by the familiar instance of the composition of *milk*. All other matters appropriated by animals as food, exist for themselves; or for the use of the vegetable or animal, of which they form a constituent part. But milk is designed and prepared by nature expressly as food, and it is the *only material* throughout the range of organisation that is so prepared. In milk, therefore, we should expect to find a model of what an alimentary substance ought to be—a kind of prototype, as it were, of nutritious matters in general. Now every sort of milk that is known, is a mixture of the four staminal principles we have described; in other words, milk always contains, besides *water*, a *saccharine* principle; a *caseous*, or, strictly speaking, an *albuminous* principle; and an *oily* principle. Though in the milk of different animals, the three latter of these staminal principles exist in endlessly modified forms, and in very different proportions; yet neither of them is at present known to be entirely wanting in the milk of any animal.

"The composition of the substances by which animals are usually nourished, favours the mixture of the primary staminal alimentary principles; since most of these substances are compounds of at least three of the staminal principles. Thus most of the gramineous and herbaceous matters, besides water, contain the saccharine and the glutinous principles; while every part of an animal contains at least albumen and oil. Perhaps, therefore, it is impossible to name a substance constituting the food of the more perfect animals, which is not essentially a natural compound of at least three, if not of all the four great principles of aliment."(a)

Appetite and satiety.—The sensations are in part taste itself, and in part sensations analogous to taste, like those which are excited by the food when appetite is wanting. The sense of appetite is heightened in winter and spring, by cold baths, by friction of the skin, by friction of the abdomen, and by the agitation to which the abdomen is subjected in exercise on horseback, as well as by muscular exertion.

Digestion excites in healthy persons a general feeling of satisfaction and pleasure, with the sensation of warmth; but these feelings are not confined to the digestive organs, of which the principal sensitive nerve is the vagus; but extend to almost all parts of the body: it is probable, therefore, that they are in a great measure owing to excitement of the sympathetic nerves, which, as will be shown at a future page, possess in a high degree the faculty of transmitting impressions made on them from one part to another.

(a) I have substituted the preceding summary of Dr. Prout's views of the classification of alimentary matters, as contained in his late work, for the less complete sketch taken by Müller from Dr. Elliotson's edition of Blumenbach's Physiology. Dr. Prout seems to have anticipated the results of recent chemical analyses, when he tells us that *albuminous aliments*, under which head he includes "the principal modifications of albumen—*gelatin*, *albumen*, strictly so called, *fibrin*, *curd*, *gluten*,"—have "certain properties in common, so as to render it probable that their ultimate composition is similar, or at least analogous." As regards albumen and fibrin, this opinion has been, as the reader will have learned (p. 100), fully verified; and to these proximate principles, so closely resembling one another, as to approach to identity, may be added casein (see note to p. 15) and gelatin. Not only has this close affinity been made manifest by a discovery of the ultimate composition of these principles, but also by that of a proximate principle, *protein*, which represents them all, and probably serves as the last reduction to homogeneity of organic nutritive matter before it becomes a part of the chyle and blood for the subsequent construction of the tissues. For any practical view of the subject, the term *albuminous*, as used by Dr. Prout, will serve to represent the substances, chiefly animal, into which azote enters.

Indigestion is a state of the digestive organs, in which either they do not secrete the fluid destined for the solution of the aliment, or they are in such a condition of irritability or atony, that by the mechanical irritation of the food painful sensations and irregular motions are excited. The local sensations of uneasiness in the digestive organs appear to have their seat principally in the nervus vagus; for any great irritation of that nerve in the œsophagus and pharynx seems to produce the same sensations of nausea as are the result of irritation of the stomach itself previous to vomiting. But the sympathetic affection of the whole nervous system in such cases is not less striking, and seems to be likewise dependent on an impression made on the sympathetic nerve.

In *hunger* and *thirst* both kinds of sensations, the local and general, are present, but the after phenomena are the direct effects of the want of nutriment and water in the system.

What is called *thirst* is, however, sometimes rather a call for the cooling influence of cold drinks, as, for instance, in the dry hot state of the air-passages, mouth, and skin produced in fevers by the increased temperature and diminished turgescence of the parts. Exhalation is in such cases often diminished, and the dryness of the surface arises from the circumstance that although blood still flows through the capillary vessels, the reciprocal action between the blood and the living tissues, which is denominated turgescence, or *turgor vitalis*, is depressed. No increased generation of caloric in the internal organs is here required to account for the elevated heat of the skin, since it would arise from the mere absence of exhalation and of the cooling effect produced by the conversion of a fluid into a gaseous body.

The final consequences of unappeased thirst are a feverish state which does not apparently differ from that of nervous fevers, and with it inflammation of the air passages.

The local sensations of hunger, which are limited to the digestive organs, and appear to have their seat in the nervus vagus, are feelings of pressure, motion, contraction, qualmishness, with borborygmi, and finally pain. These sensations have been supposed to be caused by the saliva, by the bile, by the rubbing of the coats of the stomach against each other, or by the acrid gastric juice. Dumas imagines the feeling of hunger to arise from the action of the absorbent vessels of the alimentary canal being turned upon the coats of the stomach and intestines themselves. All these suppositions are quite inadmissible. The aliment is an "adequate," or "homogeneous" stimulus (see pages 61 to 63) to the digestive organs: when this stimulus is wanting, the state of the organ is made known to the sensorium by the nerves. Brachet (*Recherches sur les fonctions du système ganglionaire.* Paris, 1830,) infers, from his experiments, that the local sensations of hunger, as well as those of appetite and satiety, cease to be felt after division of the nervi vagi, and it is possible that such is the case. The observations of Dr. J. Reid, however, lead him to conclude that animals in some instances still continue to feel hunger after those nerves have been divided. It is obvious that if the sensation of hunger is excited in the vagi nerves by the want of chyle in the system, it might still be felt after the section of those nerves, and would necessarily be referred to the stomach where the peripheral extremities of the nerves are distributed. But it would not be so easy to account for food taken into the stomach exciting the sensation of satiety, which Dr. Reid supposes may occur under the same circumstances. The sensation of hunger is put an end to, by the change which the assumption of food produces in the state of the gastric nerves, by strong impressions on the sensorium, and the active states of it excited by passions or meditation, and by the change produced in the brain itself by taking opium, &c. The long fasting to which insane persons are frequently observed to subject themselves, may in like manner be accounted for, perhaps, by their having, in consequence of the morbid affection of their sensorium, lost the perception of the local sensation of hunger which incites us to take food.

The general effects of fasting, however, are observed to be for the most part similar even in different conditions of the digestive organs. They are feelings of general debility, actual and gradually increasing loss of strength, fever, delirium, and violent passion, alternating with the deepest despondency. The temperature of the body is said to fall several degrees, though this is denied by Dr. Currie (*On the effects of Water, cold and warm, as a remedy in fever*, 1797;) to have been the case in a patient who died of inanition in consequence of stricture of the œsophagus. The respiration becomes fetid, the urine acrid and burning, and the lymphatic vessels, according to Magendie and Collard, bloody. Collard states that the quantity of their contents is increased when the animal has fasted only a short time (?), and that it afterwards gradually decreases, but that even the lacteals still carry some little lymph about the middle period of the abstinence. Contraction of the stomach ensues. The secretions cease to be formed, although the gall-bladder is full, and bile still passes into the intestine. (It does not enter the stomach, according to Magendie.) The mucus of the mucous membranes becomes less abundant, as do all substances which can be absorbed. The pus from wounds, the milk, saliva, and the poison of serpents, cease to be secreted. The urine still contains urea; for Lassaigne found that substance in the urine of a madman who had fasted eighteen days: (*Journal de Chim. Med.* 1825, *Avr.*) The mucous membranes are pale; the urinary passages are not necessarily inflamed. M. Collard states that the relative quantity of fibrin in the blood is diminished during fasting, while the proportion of solid matters due to the red particles is increased. (*Magendie's Journal de Physiol.* t. viii. p. 171.) The stomach is found much contracted after death.

Experiments on the duration of life in man and animals deprived of food, show that warm-blooded animals are least able to support the want of food. The lower animals with a hard external skeleton will live an extraordinary length of time without food: I have been informed by letter, that an African scorpion lived during the voyage to Holland and nine months after it arrived there and came into the possession of Dr. Dehaan, without taking any food. Rudolphi kept *proteus anguinus* five years; Zoys had one ten years, living in spring water renewed from time to time, and having nothing else given to it. Salamanders, tortoises, and gold-fishes may likewise be kept for years without food, and it is well known that snakes will live for six months without eating. Redi found birds sustain the want of food for from five to twenty-eight days: a seal lived out of water, and without nourishment, for four weeks; and dogs lived from twenty-five to thirty-six days without eating or drinking. Man does not generally support hunger and thirst longer than a week; though hunger alone is borne much longer, especially in disease, and above all in insanity. (See *Tiedemann, Physiol.* t. iii.) The accounts of persons having lived without taking food for months and years are, as Rudolphi with justice remarked, examples of deception.

CHAPTER II.

OF THE DIGESTIVE ORGANS.

a. Of the different forms of the alimentary canal.

It appears to be a universal characteristic in the physical structure of animals that they have an internal cavity for the production of a chemical change in the aliment—a cavity for digestion. This cavity is in most cases tubular, and open at its upper and lower extremity, but sometimes it is provided with but one, oral, opening; the remains of the food, after digestion, being expelled by the same opening by which it had been introduced. (*On the Agastrica, see Meyen, Act. Nat. Cur.* t. xvi. *Suppl.*)

The *Infusoria* have been shown by the great discoveries of Ehrenberg to possess throughout the class a mouth surrounded with cilia: but this is not all; Ehrenberg has been enabled, by feeding the creatures with coloured substances, to distinguish the different forms of their digestive organs, and to found on these differences a division of the class into primary groups. Some he finds to have neither intestine nor anus, but merely a single mouth, into which many cæcal stomachs open; this is the form of the digestive organs in the monads, &c. In others there is a complete intestinal canal furnished with mouth and anus, and communicating by narrow tubes with numerous cæcal stomachs.* The intestine sometimes describes a circle in the body of the animal, terminating near the mouth in a ciliated ring at the upper extremity of the body, as in the vorticellæ; in other instances the mouth and anus are situated at opposite extremities of the animal; while, in others, again, the situation of the mouth and anus alternates, either one or other of them being at the extremity of the body; lastly, in another group, both mouth and anus open at the abdominal surface of the body. In Loxodes cucullatus,—a polygastric animalcule with complete digestive canal,—Ehrenberg has discovered and described pharyngeal teeth.

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* The accuracy of M. Ehrenberg's statement, that the round bodies seen within the so-called Polygastric animalcules, are stomachs, has, however, been recently called in question by Mr. R. Jones (Animal Kingdom, p. 57), M. Meyen (Müller's Archiv. 1839, p. 74), and M. Dujardin (Ann. des Sc. Nat. 1838. Nov.).

In the *Rotifera*, or *wheel animalcules*, there is an intestinal canal extending from the mouth to the anus, and in some Ehrenberg has discovered a dental apparatus. Most of them have two glandular-looking organs at the commencement of the intestinal tube.*

In the *Acalepha* there is neither anus nor intestinal tube; the aliment is either conveyed by the mouth into a stomach which is ramified like a vascular system in the substance of the animal,—as in the Medusæ; or the nutriment is taken up by the absorbent tubes of the tentacula, and by these carried to the stomach,—as in the Rhizostomata; or, as appears to be the case in the Berenice and others, the food, being taken up by absorbent tubes, is distributed through ramified digestive canals, there being no true stomach. And, even in cases where there is a stomach, ramifying tubes, like vessels, arise from it, and are distributed through the substance of the animal.

In the *Polypifera*, of which some are free, others fixed, some simple and others united on a common stem, the digestive organs are in some instances simple, consisting of a cæcal sac-like stomach, which is the form in the Actiniæ, Fungi, Madrepora, Tubipora, Alcyonia, Millepora, Sertularia, and Hydræ; while in others, as in the Alcyonellæ, there is a short intestinal canal, the anus opening near the mouth.†

In the *Entozoa* the forms of the digestive cavity are exceedingly various. In the cystic worms the vesicular cavity of the body serves to fulfil the office of digestion; such, at least, seems to be the case, in the Cysticercus and Cœnurus. In the Cestoidæ, or tape-worms, the intestine is described by Mehlis to commence as a simple tube, but to bifurcate very soon. In the trematoda, or suctorious worms, there is no anus, and the intestine is ramified through the body like a vessel, though there is besides,—for example, in the Distoma,—a second system of vessels, which opens at the posterior part of the body, and which may perhaps communicate with the ramified intestinal canal by its smaller branches.‡ In the Acanthocephala the anus is again wanting, and the bifurcate intestinal canal terminates by cæcal extremities. The Nematoda, or round worms, have a simple tubular intestine provided with mouth and anus.

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* Ehrenberg, Physikal. Abhandl. der Königl. Akademie der Wissenschaften zu Berlin. 1830 and 1831.

† See Hemprich and Ehrenberg, Symbolæ Physicæ. Berol. 1831. See also Meyen, Isis, 1828. Nov. Act. Nat. Cur. t. xv. Suppl. Sharpey, Cyclop. of Anatomy, Art. Cilia and Farre, Philos. Transact. 1837, p. 388.

‡ Mehlis de Distomate hepatico et lanceolato. Götting. 1825. Laurer, Disquis. Anatom. de Amphistomo conico. Gryphiæ, 1830.

Between the *Planaria, Prostoma, Derostoma,* and other similar worms of fresh and salt water, so closely allied to the Entozoa, particularly to the Trematoda, there are, again, marked systematic distinctions in the forms of the digestive organs; the Prostoma and Derostoma having both mouth and anus, while in the Planaria there is a ramified intestine, with the mouth at the abdominal surface of the body, but no distinct anus. (*Ehrenberg, Symb. Physik.*)

In the *Radiata* there is sometimes,—as in the Holothuria and Echinoidea, &c.—an intestinal canal with both mouth and anus, which in the Holothuria are at the opposite extremities of the body; while in the Echinoidea the mouth is in the middle of the under surface, and the anus either in the middle of the upper surface,—as in the Echinus,—or at the border of the shell,—as in the Spatangus. In the Asterioidea there is merely a stomach with cæcal appendages, no intestinal canal nor anus; while in the Crinoidea the intestine and anus are again met with,—as in the Comatula,—in which the anus is placed together with the mouth at the under surface of the body.

In all the *Annelida, Crustacea, Arachnida,* and *Insecta,* there is an intestinal canal, with mouth and anus; but its form presents many varieties. We may mention, as particularly remarkable in these classes, the increase of digestive surface by means of cæca arising from the short intestinal tube in the Phalangida, (a family or tribe of tracheary Arachnida,) the dental apparatus in the stomach of Crustacea,—for example, crabs and lobsters,—and of some insects (the Orthoptera), and the complex form of the stomach in some carnivorous insects. In general, the alimentary canal of insects consists of an œsophagus, a crop, (which, however, is met with only in the Hymenoptera, Lepidoptera, and Diptera,) the gizzard furnished on the inner surface with teeth or horny ridges (which exists in the carnivorous Coleoptera, and most Orthoptera), the chylific portion of the canal which extends to the insertion of the Malpighian, or so-called biliferous vessels, and the intestine which extends from that point to the anus.

In the *Vertebrata* the stomach is ordinarily a mere dilated portion of the alimentary tube. The intestine in *fishes* is usually short, but its want of length is sometimes compensated for by folds of the mucous membrane; in the rays and sharks, for example, the internal coat of the intestine forms a spiral valve extending from the stomach to the anus, which in fishes is generally situated in front of the opening of the urinary and genital organs.

In *birds* the stomach presents a complexity of structure which is not met with in fishes, Amphibia, and reptiles. In addition to the crop, or sac-like diverticulum of the œsophagus,—an organ destined for the preparatory softening of the food, and pretty generally present in birds, being wanting only in the Scansores, Grallatores, Natatores, Insectivores, and Cursores, or birds of the ostrich kind,—the stomach itself is divisible into two parts: 1. the so-called proventiculus, or glandular stomach, a dilatation of the cardia, in the walls of which there is an entire stratum of distinct glandular follicles; and 2. the muscular stomach, or gizzard, which follows immediately upon the other. In carnivorous birds the walls of the gizzard are thinner, but they are very thick in those which feed on vegetable substances; and then the muscular coat forms two very thick lateral muscular masses, and the mucous membrane which lines their inner surface has a thick warty covering of epithelium. The large intestine is short and narrow, and has two cæca at its commencement, which are of greatest length in birds which feed on vegetable substances. The rectum, as in reptiles, opens into the cloaca, together with the urinary and genital organs.

In *Mammalia*, the distinction between those feeding on vegetables and those which live on animal substances is the point of greatest interest. The glandular stomach of birds is not met with in the class Mammalia as a distinct portion of the alimentary tube, and the only structure analogous to it is presented by the accumulation of numerous glands about the cardia in some quadrupeds,—for instance, the beaver, phascolomys, &c.*

In several *rodent animals*, such as the hamster and water-rats, the stomach is already divided into two parts. In the great *kanguruh* it has three compartments; in the *sloth* even four; among the apes the *Semnopitheci* have a compound stomach, consisting of three portions, the cardiac with smooth simple parietes, a very wide sac-like portion, and a long tubular division similar to a large intestine. The complex structure of the stomach is, however, by no means a universal character of herbivorous Mammalia; for in the *Solidungula* (the horse, ass, &c.) the stomach is simple, its different regions being distinguished merely by the extension of the epithelium from the œsophagus over the cardiac portion. In the *Pachydermata*, also, if we accept the pecari and hippopotamus, in which the stomach has peculiar appendages, or sac-like dilatations, the organ is generally of simple structure. The stomach exhibits the most remarkable complexity of structure in the ruminants among herbivorous Mammalia, and in the dolphins among those living on animal substances.

The last only of the four stomachs of the *Ruminantia* has the acid property which characterises the organ in other Mammalia. The first three cavities have a distinct lining of epithelium, and may be regarded as divisions of the cardiac portion of the stomach, and destined for the softening of the vegetable food preparatory to true digestion. The first great compartment of the stomach, the *paunch*, is characterised by the numerous flattened papillæ of its inner surface; it effects little change in the food which is in it subjected to maceration by the saliva. The second, smaller stomach, the *reticulum*, communicates freely with the paunch, and is distingushed by the honeycomb-like denticulated folds of its lining membrane. In the third stomach, the *manyplies* or *omasum*, the mucous membrane is thrown into numerous deep longitudinal folds, arranged side by side like the leaves of a book. The food having been softened in the first and second stomach, is after a certain time returned to the œsophagus and mouth, and having been a second time masticated, descends through the œsophagus into the third stomach, and thence passes by a narrow opening into the fourth, the *obomasum*, of which the mucous membrane is soft, and the form elongated almost like that of the intestine. The first and second stomachs may be regarded as diverticula from the cardiac portions of the œsophagus and stomach. The opening by which they communicate with the œsophagus can be closed so that the morsel of food is made to pass onwards directly into the third stomach without entering the first and second cavities.

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* See Sir E. Home's Lectures on Comparative Anatomy, vol. ii. and Müller, de Gland. Secernentium, penit. struct. tab. i. fig. 9, 10.

In the *Cetacea*, the complex structure of the stomach is met with both in the vegetable feeders and in those which live on animal substances. The stomach of the phytophagous manati has several compartments, and that of the zoophagous whales, also, has even five or more divisions.

The alimentary canal in the *Carnivora* is generally much shorter than in the other orders, and the distinction between the small and large intestine is in them less marked, while in most Herbivora the colon is very wide and very long. The *cæcum* also presents remarkable differences according to the kind of food which the animal takes. In general it is remarkably small in Carnivora, while in the Solidungula, Ruminantia, and most Rodentia, it is very long,—for example, in the horse it measures two feet and one half; in the beaver, two feet.

The herbivorous Mammalia afford examples of *a change from animal to vegetable food,* inasmuch as for a certain period after birth they are supported on the milk of the mother, and during that period the first stomach is small. But the changes which the alimentary canal of the larvæ of frogs undergoes is much more remarkable. These Amphibia in the larva state have an intestinal canal of very great length, and appear at that time to feed principally on vegetable substances; while at a later period, when their food consists of animal matters, the intestine is very short.

The most general inference to be deduced from the foregoing comparative review of the forms of the alimentary canal in the animal kingdom is, that vegetable substances require a much more extensive apparatus for their digestion than animal substances. The intimate connection which exists between the whole organisation of an animal and the nature of his food, has been set forth by Cuvier in so admirable a manner,[*] that I cannot refrain from giving his own words. Cuvier says, "Every organised being forms a whole, a unique, and perfect system, the parts of which mutually correspond, and concur in the same definitive action by a reciprocal reaction. None of these parts can change without the whole changing; and, consequently, each of them, separately considered, points out and marks all the others. Thus, as I have before remarked, if the intestines of an animal are so organised as only to digest flesh, and that fresh, it follows that its jaws must be constructed to devour a prey, its claws to seize and tear it, its teeth to cut and divide it, the whole structure of the organs of motion, such as to pursue and catch it, its perceptive organs to discern it at a distance; nature must even have placed in its brain the necessary instinct to know how to conceal itself and lay snares for its victims. That the jaw may be enabled to seize, it must have a certain-shaped prominence for the articulation, a certain relation between the position of the resisting power and that of the strength employed with the fulcrum; a certain volume in the temporal muscle, requiring an equivalent extent in the hollow which receives it, and a certain convexity of the zygomatic arch under which it passes: this zygomatic arch must also possess a certain strength to give strength to the masseter muscle. That an animal may carry off his prey, a certain strength is requisite in the muscles which raise the head; whence results a determinate formation in the vertebræ or the muscles attached, and in the occiput where they are inserted. That the teeth may cut the flesh, they must be sharp; and they must be more or less so, according as they will have, more or less exclusively, flesh to cut. Their roots should be the more solid as they have more and larger bones to break. All these circumstances will in like manner influence the development of those parts which serve to move the jaw. That the claws may seize the prey, they must have a certain mobility in the talons, a certain strength in the nails, whence will result determinate formations in all the claws, and the necessary distribution of muscles and tendons, it will be necessary that the fore-arm have a certain facility of turning, whence again will result determinate formation in the bones which compose it; but the bone of the fore-arm articulating in the shoulder-bone, cannot change its structure without this latter also changes. In a word, the formation of the tooth bespeaks the structure of the articulation of the jaw; that of the scapula, that of the claws; just as the equation of a curve involves all its properties; and, in taking each property separately as the basis of a particular equation, we should find again both the ordinary equation, and all the other certain properties; so the claw, the scapula, the articulation of the jaw, the thigh-bone, and all the other bones separately considered, require the certain tooth, or the tooth requires them reciprocally; and beginning with any one, he who possessed a knowledge of the laws of organic economy would detect the whole animal. We see, for instance, very plainly, that hoofed animals must all be herbivorous, since they have no means of seizing upon their prey; we see, also, that having no other use for their fore-feet than to support their bodies, they have no occasion for so powerfully framed a shoulder; whence we may account for the absence of the clavicle and the acromion, and the straightness of the scapula: not having any occasion to turn the fore-leg, their radius will be solidly united to the ulna, or, at least, articulated by a hinge-joint, and not by ball and socket, with the humerus: their herbaceous diet will require teeth with a broad surface to crush seeds and herbs; this breadth must be irregular, and for this reason the enamel parts must alternate with the osseous parts; this sort of surface compelling horizontal motion or grinding the food to pieces, the articulation of the jaw cannot form a hinge so close as in carnivorous animals; it must be flattened, and correspond with the facing of the temporal bones, more or less flattened; the temporal cavity, which will only contain a very small muscle, will be small and shallow."

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[*] Cuvier, Revolutions of the surface of the Globe. English translation, Whittaker, London, p. 59.

b. Of the membranes forming the coats of the alimentary canal.

The alimentary canal has an external serous investment derived from the peritoneum, a muscular coat lying under the serous coat, and a tunica propria, which forms a kind of fascia, or framework, on the outer surface of which the muscular fibres lie, while to its inner surface *the mucous membrane* is attached.

The structure of the villi of the small intestine has been already described, and their relation to the process of lacteal absorption discussed. (See pages 271–2.)

The glands of the mucous membrane of the intestinal canal remain to be considered. Three forms of these glands have been distinguished:—

1. *The follicles of Lieberkühn*—foramina, or depressions, so small as not to be visible without the aid of a glass, which are spread over the whole extent of the mucous membrane of the *small intestine*, and are in such number that when sufficiently magnified they give to the membrane the appearance of a sieve. (They have been already described at page 272.) To the same class, perhaps, belong the simple tubular follicles described by Dr. Boehm (*De Gland. Intestin. Struct. Penit.* Berol. 1835,) as occupying the whole extent of *the mucous membrane of the large intestine*, and represented by him as seen in a section of the membrane to be arranged perpendicularly side by side, their cæcal bases resting on the subjacent vascular membrane, while their orifices, which are so minute as to be scarcely visible without the aid of a glass, are separated by spaces but little larger than the openings themselves. There are other follicles of the large intestine which are larger and much less numerous, and which, under the name of glandulæ solitariæ, have been confounded with the duodenal glands of Brunner. Their form is that of a simple round cavity. They are most numerous in the cæcum and appendix.

The mucous membrane of the stomach has a structure somewhat similar to that described by Boehm, as belonging to the large intestine. It has been made the subject of examination by Dr. Sprott Boyd.* He describes it as having here and there a velvety appearance, from the presence of minute folds, or fold-like villi, but as being throughout characterised by small regular cells, the diameter of which was generally from $\frac{1}{200}$th to $\frac{1}{350}$th of an inch; but near the pylorus $\frac{1}{100}$th of an inch. In the bottom of the cells a number of minute openings were visible; and, on making a vertical section of the membrane, it was seen to be composed of perpendicular fibres, which Dr. Boyd believes to be tubes opening into the cells. In the pig he could distinguish the cavity of the tubes.

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* Inaugural Essay on the structure of the mucous membrane of the stomach, by Sprott Boyd. Edinb. 1836.

The fact of the follicular structure of the mucous membrane of the stomach has been fully confirmed by the observations of Bischoff, (*Müller's Archiv.* 1838, p. 503,) and Purkinje, (*Isis*, 1838, No. 7.) The former anatomist found that the follicles most frequently were not simple tubuli, but had towards their inferior closed extremity a sacculated or racemose structure; while Purkinje directed attention to the fact that the walls of the follicles were, like the secreting canals of glands, formed of a stratum of nucleated granules, and that the same granules, with a more or less mucous fluid, constituted the solvent secretion of the stomach.

The whole surface of the mucous membrane of the stomach in the pig, as stated by M. Wasmann, (*De digestione nonnulla. Diss. Inaug.* Berol. 1839,) and also in the ox and human subject, is in the intervals of digestion covered with cylinder epithelium, which during digestion seems to be separated and to become mixed with the secretion of the follicles. While the process of digestion is going on, the secretion on the surface of the mucous membrane contains the nucleated globules or cellules described by M. Wasmann; in the pig these globules appear to be poured out only by the cellular organs of the middle region of the stomach; but their formation is not essentially dependent on the cellular structure of those organs, for the translator has seen the same globules in perfectly simple tubuli of the mucous membrane of the human stomach; and, on the other hand, he has twice observed the cellular organs of the pig's stomach invested internally with cylinder epithelium. The translator is inclined to believe that the open mouths of the tubular follicles, ordinarily described as being visible on the mucous surface of the stomach, exist only during the period of digestion. For, twice in the pig, and once in the human subject and ox, when the stomach had not been engaged in digestion at the time of death, he has seen the follicles terminate at the surface of the mucous membrane by apparently closed extremities, which in some instances were prominent, like short papillæ. Dr. Boyd mentions such papillæ as being sometimes seen in the rabbit and in the hedgehog, and states his belief that those seen in the rabbit are of a tubular structure. The representation which Bischoff gives of the epithelium of the dog's stomach, shows that he also had seen the extremities of the tubuli in their closed condition.(*a*)

(*a*) Doctor Horner, of the University of Pennsylvania, whose patience in investigating and accuracy in describing the minute structure of the organs are so well known, has put on record (*Am. Jour. of the Med. Sciences*, vol. xvi.) the result of his observations on the structure of the mucous coat of the alimentary canal. He regards this coat as composed in a healthy state of "a cribriform intertexture" or meshes of veins, while the arteries enter only inconsiderably into their composition, to an amount in some measure comparable to the presence of the arteries in other erectile tissues, as the corpus spongiosum and cavernosum penis. "If the corpus spongiosum were in fact spread out into a thin membrane, so as to line a

2. *Brunner's glands*—follicles visible to the naked eye, distributed singly in the membrane, and most numerous in the upper part of the small intestines.

Very different structures have been confounded under the name of

hollow viscus, it would present no very exaggerated representation of what I (says Dr. Horner) have denominated the *superficial venous layer* of the alimentary canal, it being also admitted that within the circuit of every anastomosis a follicle was formed. Viewed in the preparations of the mucous membrane of the small and large intestines which I have, these follicles appear like puncta lachrymalia disseminated by thousands over every square inch, and existing so invariably upon every part, that as I have stated, the smallest calculation of their numbers puts them at from forty to fifty millions."

The meshes of the first or superficial venous intertexture are exceedingly minute and vary in a characteristic manner in the stomach, small intestines and colon. "Nothing short of an entirely successful injection will exhibit this venous anastomosis, as described; and it may be seen either by injecting a vein, or an artery, provided the injection passes from the artery into the veins; but the latter process is the least desirable, because we lose the benefit of a distinction of colour between the two sets of vessels."

Doctor Horner has demonstrated the existence of an epidermis in the alimentary canal, from the cardiac orifice of the stomach to near the anus, by the following process:—"Tear off the peritoneal coat—invert the part and inflate it to an emphysematous condition, the epidermis will then be raised as a very thin pellicle, and may be dried in that state; but as this pellicle retains the air, we hence infer that it lines the follicles, and is uninterrupted by any perforations. This epidermis, if the part be previously injected perfectly, shows dots of injecting matter, but no arborescence if it be inflated up from the veins. In so doing the villi disappear, are in fact unfolded.

"The villi cannot be seen to any advantage except they be erected by an injection, in which case those of the upper part of the small intestines are found to run into each other very much like the convolutions of the cerebrum, and to press upon each other's sides in the same way. Some of them, however, are merely semi-oval plates, the transverse diameter of which exceeds the length. At the lower end of the small intestine they become simply conical projections, somewhat curved, with the edges bent in, and they retain this mechanism until they entirely disappear near the ileo-cœcal valve. In the whole length of intestine there is, however, every variety of shape, from oblong curved and serpentine ridges, to the flattened cone standing on its base; the first condition changing gradually to the last in the descent of the bowel. Conformably to this definition of villi, none exist either in the stomach or colon, for there we have only the venous mesh. The villi of the jejunum are about the thirtieth of an inch high, and those of the ileum about one-sixtieth."

Doctor Horner believes that in epidemic cholera the epidermic and venous lining of the alimentary canal is exfoliated, whereby the extremities of the venous system are denuded and left patulous. This pathological view corresponds with the physiological one referred to in the text, by which the cylinder epithelium covering the follicles is separated and becomes mixed with the secretion of these latter during digestion. It is only at this time that the follicles are believed to be open.

In the stomach, according to Dr. Horner, the follicles vary very much in size, and there is an arrangement whereby many of the smaller ones are seen to open into the larger; on an average about two hundred and twenty-five are found upon every eighth of an inch square, which would give of course to an inch square sixty-four times that amount, or fourteen thousand four hundred follicles, and conceding the whole stomach to present an area of ninety inches, which is probably below the mark when this organ is moderately distended, as exhibited in the preparation upon which this calculation is founded, the entire number of follicles is one million two hundred and ninety-six thousand.

Touching the *size* of the follicles, we learn that "in the stomach, the largest of these follicles is about $\frac{1}{58}$th of an inch in diameter, and the smallest about $\frac{1}{250}$th.

the glands of Brunner. Dr. Boehm has pointed out that the bodies described by Brunner, and regarded by him as analogous to the pancreas, do not exist lower down in the intestinal canal than the end of the duodenum, or commencement of the jejunum. They are little solid glands formed of several minute lobules, lying under the mucous membrane, and, by their great number near the pylorus, constituting there a continuous layer in the coats of the intestine.

3. The so-called *glandulæ agminatæ*, or *glands of Peyer*,—which have their seat along that side of the intestine which is opposite to the insertion of the mesentery. The nature of these thickened, generally oval patches of the mucous membrane, has, up to the present time, been quite a mystery. The following account of them is the result of Dr. Boehm's researches, and I may remark that I have verified his observations. For the examination of the glands of Peyer, the intestine of healthy persons must be selected; the intestine of those who have died suddenly is therefore to be preferred. In many chronic diseases, particularly when they affect the intestinal canal itself, the organs in question become very much altered; and if examined in that state, a false idea of their structure is obtained. Whenever they present the appearance of shallow cells arranged side by side, they are not in a healthy state, for their form has naturally no analogy with that of open cells or follicles. If one of the patches of Peyer's glands is examined with the microscope in a healthy intestine, after the surface has been gently washed, and the gland itself cleansed by means of a soft camel's hair pencil, it is readily seen that the thicker aspect of the membrane in these patches is in part owing to the size and number of the villi, which are here

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In the colon the largest is about $\frac{1}{125}$th of an inch in diameter, and the smallest about $\frac{1}{150}$th. In the small intestines their size varies in about the same ratio as in the colon, but they are much more irregular in shape, being scattered more in groups in consequence of the villi intervening; some of them penetrate obliquely towards the foundations of the villi, hence when examined from the exterior, their distribution is more regular, and they are seen lodged in the cellular coat of the gut."

Doctor Horner is not inclined to believe in the secreting function of the follicles —he argues as follows:—"If they are simply secernents of mucus, the number, one would think, is much greater than so limited a secretion requires—moreover, why is it that they become smaller and less numerous towards the lower end of the large intestine, where greater lubrication is required for hardened fæces; in addition, are not the glands of Brunner, (solitariæ,) and of Peyer, (agminatæ,) amply sufficient to furnish the required mucus? Again, after most sedulous observations upon the villi of all kinds, finely erected by my injections, and placed under most accurate, simple, and compound microscopes, I find invariably a polished reflecting surface, uninterrupted by foramina, either at their ends or sides, while many of these follicles are found passing obliquely into their bases. An excellent Woollaston's doublet, which makes the villi of the ileum appear an inch long, exhibits them with a polished translucent surface, without foramina, except where a villus from accident has been broken, a contingency readily recognised by one in the habit of viewing them. Finally, if the lacteal foramina of Lieberkühn and others, do exist in fact, why is it that the raising of the intestinal epidermis by inflation does not exhibit these foramina by the air escaping through them, but on the contrary, admits of a dried preparation in that state, the villi being completely effaced?"

Compare these views with those cited in the text on the structure of the villi of the intestines, p. 271-2.

broader than in other parts, particularly at their root. The mucous membrane between the villi presents here, as in other parts of the intestine, the numerous follicles of Lieberkühn; but in addition to these there are seen circular white spots, about one line in diameter, in which the mucous membrane is generally free from villi; on very few there are traces of very short villi. In the human subject these spots are only slightly raised; it is very seldom that the centre of the spot forms a short pyramidal white point. In other animals, particularly in the dog, cat, and rabbit, they are more elevated, and in the dog look like white papillæ; in the cat and rabbit they are surrounded by a circular furrow, and have a flattened surface, so as to resemble the papillæ vallatæ of the tongue. Each of these white spots, of which several are contained in a patch of the glands of Peyer, is surrounded by a zone of openings like those of Lieberkühn's follicles, except that they are more elongated; and the direction of the long diameter of each opening is such that the whole produce a radiated appearance around the white spot. The number of openings in each zone is about ten, and they are generally arranged in a circular manner. No opening is visible in the surface of the white spot, except in birds; in them there is a small opening. (In my work on the glands, I mentioned and gave a representation of the appearance of Peyer's glands, which we have here described after Boehm; but which I had noticed only in the cat.) Dr. Boehm tried in vain, both in the human subject and other animals, to express any secretion from the white bodies through an external opening, as he would have been able to have done if they had been follicles; nor did pressure force the contents of the white bodies out through the openings which form a zone around each of them. On rupturing the surface of one of the bodies, a cavity is opened which corresponds in extent to that of the white spot previously seen, and is of considerable depth, though less deep than broad. The contents of the cavity are a greyish-white mucous matter, containing granules smaller than the ordinary particles of mucus. The membrane which covers in the cavity is extremely thin. It appears, then, that there are no large follicles with open mouths or cells in the patches of the so-called "Peyer's gland," but merely sacculi, of which the nature is unknown. The appearance of cells or follicles is not produced until the delicate membrane which shuts in these sacs is destroyed, as so frequently happens in disease of these organs. The solitary glands of the lower part of the small intestines, which have been confounded with the glands of Brunner, are, according to Boehm, single sacculi, similar to those which, when aggregated, form the patches of Peyer. They are surrounded with a zone of openings, contain a white matter, and become diseased, in the same cases as the aggregated sacculi, but differ from them in being beset with villi.

The *third coat* of the digestive organs is formed by the contractile, fibrous, or muscular layer which is continued from the pharynx to the anus, and sends prolongations on the efferent ducts of the glands which open into the canal.

The *serous or peritoneal coat* belongs only to that part of the canal which lies within the abdominal cavity. The intestinal tube, as well as the liver and spleen, is thrust, as it were, into the peritoneal sac, carrying before it a part of the membrane, which, after investing it, forms at its posterior border a double suspensory band or mesentery. Nearly the whole of the intestinal canal, with the exception of the duodenum, has a mesentery, or band of this kind. I have elsewhere pointed out,* that in the earliest stage of embryonic life the stomach likewise has a distinct suspensory band (a mesogastrium), which at a later period undergoes a remarkable change, being converted into a sac, the great omentum. It is not till the third or fourth month of fœtal life that the great omentum and transverse mesocolon become continuous. In many Mammalia,—as the dog, cat, hedgehog, rabbit, and horse,—there is no connection between the stomach and colon, the great omentum or mesogastrium in them passing backwards to be attached to the vertebral column without being connected with the mescolon, which arises from the vertebral column quite separately: and the same is the condition in the human embryo in the earlier stages of fœtal life.

The omentum can perform no very important part in the function of the digestive organs, since in many animals it has not the same anatomical connections, and is represented merely by a loose band extending from the stomach.

CHAPTER III.

OF THE MOVEMENTS OF THE ALIMENTARY CANAL.

The muscular coat of the alimentary tube is one of that series of contractile organs, of which the motion is involuntary and dependent on the sympathetic nerve. The cerebro-spinal nervous system has but a limited influence over it; but this influence is evidenced by manifold sympathies which exist between the digestive apparatus and the brain and spinal marrow.

The commencement and termination only of the canal have muscles which are subject to cerebro-spinal nerves and the will; such as the muscles of the mouth, and the muscles moving the lower jaw and pharynx, for mastication and in part deglutition, on the one hand, and the muscles about the anus, for exoneration on the other.

I consider it unnecessary to explain the movements of sucking, of the prehension of food, and of mastication. (*On these movements, see Treviranus, Biologie*, t. iv. 311.) The internal causes of such instinctive motions as the *sucking of new-born children* must remain enigmatical. It is difficult in this case to remain satisfied with Cuvier's theory of "instinct;" viz. that animals still so young are impelled to these actions by a dream of images, which, independently of their will, is being constantly called up in their brain,—by an innate idea, as it were, which arises out of their organisation or their necessities, just as the equation of a curve involves in it all the properties of a curve. We may, however, for the present, content ourselves with supposing that in the sensorium of the infant there exists an irresistible impulse to the performance, when possible, of the motions of sucking; and in accordance with this we find that infants, sometimes immediately after birth, suck even their own fingers: and Mayer has observed that after the head of young animals has been separated from the trunk, a finger introduced between the lips is seized. Further observations on the nature of these movements in new-born infants will be found in a subsequent part of the work.

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* Meckel's Archiv. 1830, page 395.

We shall now treat more at length of the movements of deglutition, of the movements of the stomach—rumination, vomiting, and eructation—of the movements of the intestines, and of the expulsion of the fæces.

1. *Deglutition.*—In deglutition there are three acts: in the first, the parts of the food collected to a morsel glide between the surface of the tongue and the palatine arch till they have passed the anterior arch of the fauces; in the second act, the morsel is carried past the constrictors of the pharynx; and in the third, it reaches the stomach through the œsophagus. These three acts follow each other with extreme rapidity; the first is performed voluntarily by the muscles of the tongue, under the influence of the hypoglossal and glosso-pharyngeal nerves. The second also is effected with the aid of muscles which are in part endued with voluntary motion, such as the superior and inferior muscles of the soft palate; but it is nevertheless an involuntary act, for it takes place without our being able to prevent it, as soon as a morsel of food, drink, or saliva is carried backwards to a certain point of the tongue's surface. The third act is executed, independently of the will, by muscles, of which the contractions are always involuntary.*

The third act of deglutition is perfectly involuntary, being performed by the muscular fibres of the œsophagus, which are not in the slightest degree capable of voluntary motion. The muscles which perform the second act, viz. the muscles of the tongue and pharynx, are, on the contrary, capable of executing voluntary movements; and indeed, if the fauces are moist, although there be no morsel to swallow, deglutition can be performed voluntarily, although not many times in succession. A part of the movements of the second act of deglutition, as the approximation of the sides of the posterior palatine arch, may also be performed voluntarily, without the whole process of deglutition necessarily following. By means of a mirror we may convince ourselves that we have some voluntary influence over the muscles of the fauces and pharynx, independently of deglutition. But if several of these movements, for instance, that of the tongue and that of the posterior palatine arch, are excited, either voluntarily or by the contact of a stimulus, the action of the whole group of muscles belonging to deglutition, with the constrictors of the pharynx also, ensues, and any portion of food, drink, or saliva, which has passed beyond a certain limit in the mouth, is swallowed without our being able to prevent it.

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* See Dzondi, Die Functionen des weichen Gaumens, Halle, 1831.

It appears certain that both the second and the third acts of deglutition are, as Dr. Marshall Hall (*Mem. on the Nervous System*, p. 83,) pointed out, always excited or reflex movements, and that when they seem to be performed voluntarily, although there is no food to swallow, saliva constitutes the necessary stimulus. According to this view, it is easy to understand why, if there is no food in the mouth, the fauces must be moist, and also why the movement cannot under these circumstances be repeated many times in succession. The nerves which convey to the medulla oblongata the impression which excites the movements of deglutition, are, according to Dr. Reid, (*Ed. Med. & Surg. Journ.* vol. li. p. 273,) the glosso-pharyngeal, those branches of the fifth which are distributed to the fauces, and probably those branches of the superior laryngeal nerve which reach the pharynx; while the motor influence transmitted from the medulla is conveyed by the pharyngeal branches of the vagus; by the branches of the hypo-glossal nerve, distributed to the tongue, thyro-hyoid, sterno-hyoid, and sterno-thyroid muscles; by the motor filaments of the recurrents ramifying in the muscles of the larynx; by some branches of the fifth supplying the elevator muscles of the lower jaw; by the branches of the portio dura which ramify in the digastric and stylohyoid muscles and muscles of the lower part of the face; and probably by some branches of the cervical plexus which unite with the descendens noni; all the muscles supplied by the nerves here enumerated being engaged in the function of deglutition. Dr. Reid's experiments (*Ibid.* vol. xlix. p. 150; vol. li. p. 274 and 329,) lead him to believe that both the incident and reflex motor nervous action are in the œsophagus conveyed by filaments of the vagus nerve, at least in the rabbit.*

In the *true serpents*, in which the superior maxillary bones can be in some measure separated from each other like the two halves of the inferior maxilla, and in which, by means of the long ossa quadrata extending from the movable temporal bones to the lower jaw, the throat is capable of great dilatation, the act of swallowing consists, as Rudolphi aptly remarked, in the organs of deglutition being drawn over the bulky prey.

Influence of the epiglottis in deglutition.—M. Magendie* has confirmed the observation made originally by Galen that the rima glottidis itself is closed during deglutition. But he has gone too far in admitting that removal of the epiglottis does not prevent deglutition being performed. Even allowing this conclusion, which M. Magendie has deduced from experiments on animals, to be correct, it is equally certain, as the numerous records of cases in which the epiglottis had been lost by ulceration, and Reichel's experiments (*De usu epiglottidis.* Berol. 1816,) show, that the movements of deglutition are thereby impeded.*

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* For further information respecting the functions of the vagus nerves, see the Fourth Book, 2d Section, Chap. II.

* Mémoires sur l'usage de l'Epiglotte dans la Déglutition. Paris, 1813.

In cetaceous animals, the upper portion of the larynx, which in these animals is bill-shaped, is drawn up towards the nasal cavities during swallowing; and the food, pressed backwards by the tongue, passes by its sides into the pharynx. No animals except Mammalia have a velum palati, or, with few exceptions, an epiglottis.

2. *Movements of the œsophagus.*—M. Magendie has observed the singular fact of the occurrence of rhythmic contractions of the lower part of the œsophagus independently of deglutition. I have myself since seen these contractions; they proceed downwards with great rapidity towards the cardiac orifice of the stomach, and continue about thirty seconds; according to M. Magendie, their duration is longer in proportion to the fulness of the stomach at the time, being sometimes as much as ten minutes. The contraction, according to my observation, passes gradually into a state of relaxation, which is again succeeded by contraction. While the œsophagus was contracted, M. Magendie was unable to force any of the contents of the stomach into it; but, during its relaxed state, fluids escaped into the œsophagus from the stomach by the force of gravity alone, and were either expelled by the mouth,—which, however, happened rarely,—or, which was usually the case, were repelled into the stomach by the renewed contraction of the œsophagus. It is evident, therefore, that the cardiac orifice cannot be regarded as at all times strongly closed. It is probable that the relaxation of the œsophagus is more frequent in dyspepsia, and, if so, it will be easy to explain the occurrence of eructation—the rising of air and food into the mouth—in persons labouring under it, whether we attribute the escape of the ingesta from the stomach to contractions of that viscus at the moment of the relaxation of the œsophagus, or to diminution of the capacity of the abdominal cavity consequent on the contraction of the diaphragm.

The experiments of Magendie, Legallois, and Beclard, have demonstrated that in the act of vomiting the œsophagus performs an anti-peristaltic motion, the reverse of that which it executes in deglutition. When vomiting had been produced by the injection of tartar emetic into the veins, the anti-peristaltic motions of the œsophagus still continued, even though it had been separated from the stomach. (*Lund. loc. cit.* p. 15.)

3. *Movements of the stomach during digestion.*—The contractions of the strong muscular gizzard of the granivorous birds must be very forcible, and the stomach of many Crustacea, and of orthopterous insects, has certainly a mechanical action; but the motions of the membranous stomach of other animals and man appear to be, in the healthy state, very feeble. When we open animals still living, we always observe, it is true, that the stomach embraces tightly its

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* On this subject, consult Rudolphi's Physiologie, ii. 378; and Lund, Vivisectionem; Copenhagen, 1825, p. 9.

contents, but yet it presents a most striking contrast to the incessant peristaltic motions of the intestines, which are especially active under the stimulus of the air.

Tiedemann and Gmelin state that they have excited contractions of the stomach by mechanical irritation of the nervus vagus; but neither irritation of the nervus vagus in rabbits, dogs, and carnivorous birds, nor irritation of the cœliac ganglion in the rabbit, has in my experiments appeared to exert the slightest influence on the stomach. The irritation must be applied to the stomach itself, and it then produces immediate contraction.

In Dr. Reid's experiments* it frequently happened that muscular contractions of the œsophagus induced by irritating the nervus vagus in the neck, extended over the cardiac extremity of the stomach; where, however, they were evidently slower, and more prolonged and vermicular than in the œsophagus. Dr. Reid is himself doubtful whether these movements of the stomach depend on the direct influence of motor fibres of the vagus.

It is evident, therefore, that those writers must greatly err, who ascribe much importance to the motions of the stomach in effecting the division of the food. I have never seen the peristaltic motions of the stomach distinctly; and shall therefore give M. Magendie's description of them.†

The stomach in the first period of digestion is uniformly distended, but the whole extent of the pyloric portion afterwards contracts; the chyme into which the food is converted collects in the pyloric portion, while the portion of food which has been less acted on, remains in the splenic extremity of the stomach. The peristaltic motions, which are stated by M. Magendie to continue even after the nervi vagi have been divided, are described as follows:—After the stomach has been for some time motionless, the gastric end of the duodenum contracts, then the pylorus, and the pyloric portion of the stomach, by which means the chyme is pressed towards the splenic portion. But the pyloric portion having become relaxed so as to permit the chyme to enter it again, now contracts from left to right, impelling the chyme towards the duodenum, and as much of the food as has undergone the necessary solution in the stomach passes through the pylorus into the intestines. These motions are repeated several times, then cease, to be renewed after a certain interval. While the stomach is full, the motions are limited to the region of the pylorus; but, in proportion as it empties itself, the motions become more extended, and, when the organ is nearly empty, they are seen even in the splenic region.

Schultz (*De Alimentorum Concoctione.* Berol. 1834,) imagines that where the stomach has a dilated fundus, as in the rabbit and horse, its motions are such as to cause the food to perform a circular movement along the two curvatures; while in the carnivora, in which the fundus or splenic extremity is less dilated, the food is thrown backwards and forwards to and from the pylorus; and hence it is, he supposes, that the former animals vomit with difficulty, the latter more readily.

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* Edin. Med. and Surg. Journal, vol. li. p. 308; and the American republication, in volume form.

† Préc. élément. de Physiol. 2d edit. t. ii. p. 87. Dr. Milligan's Translation, 4th edit. p. 286.

The motions of the stomach have been observed by Dr. Beaumont in a man who, in consequence of a gun-shot wound, had a considerable opening in the stomach, the margins of which had united with the borders of a wound in the abdominal parietes.*

He found that, when the digestion was not going on, the stomach was contracted; that the food, as soon as it entered the stomach, was moved from the fundus along the great curvature from left to right, and then along the lesser curvature from right to left. He perceived the effect of the same motions in the changes of position which the bulb of a thermometer introduced into the stomach underwent. These circular motions occupied from one to three minutes. They increased in rapidity as the process of chymification advanced.

Dr. Beaumont observed, likewise, that the beginning of the conical part of the stomach, about three inches from the small extremity, was the seat of peculiar contractions and relaxations. The bulb of the thermometer, when placed at that point, was tightly embraced from time to time, and retracted towards the pylorus for a distance of three or four inches.

During the first period of digestion the pyloric orifice seems to be quite closed. Its contraction is, according to Wepfer, and Tiedemann and Gmelin, sometimes so strong, that, even when the stomach is separated from the intestines, none of its contents escape. Mr. Abernethy, too, states that in the human subject fluids do not at first pass at all readily through the pylorus; for in the case of a person who had been poisoned with opium, and into whose stomach a large quantity of fluid had been injected during life, all the fluid was found to be still retained in the stomach after death. M. Magendie believes that the greater part of the fluid taken into the stomach is absorbed directly from it; nevertheless he remarks that in the horse the water taken into the stomach passes quickly through the pylorus, and so finds its way as far as the capacious cæcum, and that even the solid food escapes in part through the pylorus. Mr. Coleman gave a horse to drink, and after the lapse of six minutes the water was found to have passed through the pylorus and small intestines, even as far as the cæcum. (*Abernethy's Physiological Lectures*, 180.)

Towards the termination of the digestive process the pylorus seems to offer a more feeble resistance to the passage of substances from the stomach, for it is known to allow the transit even of undigested substances, such as cherry-stones, and other larger bodies. The central constriction of which the stomach was by Sir E. Home imagined to be the seat during digestion, has never been actually observed. Neither Tiedemann nor I have seen anything of the kind in dogs.

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* Experiments and Observations on the Gastric Juice, and the Physiology of Digestion, by W. Beaumont. Boston, U. S. 1834. Reprinted with notes by Dr. A. Combe. Edinburgh, 1838. See also Dr. Dunglison's Physiology.

4. *Rumination.*—In ruminating animals the œsophagus opens immediately into the first and second stomachs, but is continued onwards to the third stomach in the form of a groove, or half canal, with thick lips. It appears from the observations of Flourens (*Revue Encyclopédique;* Paris, Nov. 1831, p. 542,) on the sheep, that the food, whether it consists of grass, oats, or turnips, passes at once into the first and second stomachs simultaneously. A finely divided substance—as a mash of chewed turnips—was given to a sheep, and it was found to pass into the first and second stomach while a small portion reached the third. The food, softened by the action of the saliva, and the secretions of the first and second stomachs, is returned from them, by a movement like that of eructation, to the mouth, and, after being a second time chewed, is again swallowed. With the view of discovering what takes place in this second deglutition, Flourens made into the different stomachs in different animals artificial openings, which he could close when he did not wish to observe what was going forward within. By this procedure he found that, when the food is swallowed the second time, a part of it still passes into the paunch and reticulum, but that a large portion follows the œsophageal groove or canal into the third stomach.* Flourens offers the following explanation of the different course taken by the food before and after rumination:—When first swallowed, the morsels, he says, are large, and dilate the œsophagus so as to diminish the groove leading from it to the third stomach, and therefore necessarily enter the paunch. After rumination, however, the food is soft; and, without dilating the œsophagus, follows the groove which leads to the third stomach, although a small portion may still enter the first. If the rhythmic contractions of the lower part of the œsophagus during digestion, observed by M. Magendie and myself in other animals, take place likewise in ruminants, they would cause the lips of the groove leading to the third stomach to meet so as to form an entire canal, through which food finely divided by rumination would pass, though the large morsels of food, when first swallowed, would dilate it.†

With respect to vomiting in the Ruminantia, M. Flourens found that, while the first two stomachs have the power of returning the food to the mouth for rumination, the fourth stomach, by which the act of vomiting is performed, is with very great difficulty excited to execute the necessary movement.‡

5. *Vomiting.*—Vomiting is an anti-peristaltic motion of the sto-

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* According to M. Haubner (Ueber die Magenverdauung der Wiederkaüer nach Versuchen, 1837–8, and Müller's Archiv, 1838, p. clxvi.) the food after rumination again enters the first stomach and is by it transferred in successive portions to the third stomach. The main facts relative to the course taken by the food in ruminating animals, are described by Haubner nearly in the same manner as by Flourens.

† See also Berthold, Beiträge zur Anat. Zoot. u. Physiol. Gött. 1831.

‡ See the paper of M. Flourens in the Ann. des Sc. Nat. t. viii. p. 50.

mach and œsophagus, and sometimes of a part of the intestines likewise, attended with nausea, and accompanied by violent contractions of the abdominal muscles and diaphragm; it is excited by any violent irritation acting either immediately upon the pharynx, œsophagus, stomach, or intestine, or upon the nerves going to them; and it takes place also when substances capable of irritating the organs which we have named are introduced into the circulation from other parts of the system. Thus, vomiting is excited by mechanical irritation of the pharynx by means of a feather or the finger, or even by a morsel of food retained too long at that part; by all substances which irritate the stomach either mechanically or chemically; by inflammation of the stomach or intestinal canal; by the strangulation of a hernia, or intus-susception of a portion of intestine; by irritation of the brain, or interruption of the cerebral influence in consequence of division or ligature of the vagi nerves; sometimes even by the movements accompanying coughing; and, lastly, by injuries to the head, and the injection of tartar emetic into the veins. All substances which, when their action is moderate, promote the peristaltic motions of the irritated parts, by a more violent operation cause these motions to become reversed, and by nervous sympathy excite other parts not previously acted on to concur in the production of vomiting. The state of the posterior palatine arch is stated by Dzondi to be the same during vomiting as in deglutition, with the exception that the inclined plane formed by the approximation of the sides of the arch to each other is more raised, and that the uvula is shortened by the action of its muscles. This arrangement of the parts directs the matters vomited into the mouth, and prevents their entering the nostrils; although, on account of the sides of the posterior arches, even when drawn together, not meeting accurately at the lower part, a passage is left from the pharynx to the posterior nares, and matters vomited are therefore sometimes thrown into the latter cavities. Carnivorous animals vomit readily, the horse with great difficulty.

Action of the stomach in vomiting.—The opinion that the stomach itself has no share in the act of vomiting, which had been already advanced by Bayle, Chirac, Senac, and John Hunter, but was refuted by Haller, has been again revived by M. Magendie, who maintains that the stomach is itself quite passive during vomiting, and that the expulsion of its contents is effected solely by the pressure exerted upon it when the capacity of the abdomen is diminished by the contraction of the diaphragm and abdominal muscles. M. Magendie injected tartar emetic into the veins of dogs, and in other instances gave it by the mouth, but he never saw the stomach itself contract; and if in such cases he drew the stomach out of the abdominal cavity, vomiting was prevented until he returned the viscus to its natural situation, when vomiting immediately ensued. Pressure with the hand had the same influence as the abdominal muscles; and even the action of the diaphragm alone, pressing against the linea alba, was sufficient to produce vomiting when the abdominal muscles had been cut away. Division of the phrenic nerve put a stop to the vomiting. M. Magendie states, that, when the stomach was removed, and a pig's bladder connected with the œsophagus in its stead, vomiting was produced in the same way as when the stomach itself remained uninjured.

M. Magendie's conclusions were controverted, however, by M. Maingault, who stated that he had seen vomiting occur when both the diaphragm and abdominal muscles had been divided. This gave rise to further investigation, and the committee appointed by the Academy of Paris found, that without external pressure on the stomach vomiting could not take place, but that this pressure need only be very slight; for that, after the abdominal muscles had been divided, and the diaphragm paralysed, fluid could be pressed from the stomach into the œsophagus by the inferior ribs being drawn down upon the epigastric region: they perceived no motion of the stomach itself, except the circular contractions in the neighbourhood of the pylorus, which, they say, occurred independently of the act of vomiting(?). Rudolphi, on the contrary, saw such motions of the stomach during vomiting after the abdominal muscles had been divided.* Magendie's experiment with the pig's bladder does not prove much; and Rudolphi justly remarks that the tartar emetic injected into the veins in this experiment must have excited antiperistaltic motions of the œsophagus, by which the contents of the stomach might be, as it were, pumped up, and that the quantity of the fluid expelled was in fact very small. The experiment, indeed, loses all its apparent importance when we consider that the condition which ordinarily prevents the esçape of the contents of the stomach into the œsophagus,—namely, the contraction of the lower extremity of this latter,—would not exist when the œsophagus was cut through, so that from the slightest cause any fluid would escape through it. An important circumstance, which has hitherto been too much disregarded, is the existence of a kind of imperceptible contraction of the whole stomach, by which its entire volume is diminished without individual parts being seen to contract. I have often observed such a contraction of the stomach when vomiting was not taking place. The contraction of the stomach during vomiting appears to me to be an indubitable fact, for it can be felt by the person about to vomit, although it has not so great a share in the production of vomiting as has been ascribed to it; for the stomach is able to propagate the irritation applied immediately to itself to other muscles.

Action of emetics.—The propagation of local irritation of the stomach by sympathy to other muscles,—particularly the abdominal muscles and diaphragm,—is no longer a mere hypothesis; I repeatedly found that I could produce contraction of the abdominal muscles in a rabbit by lacerating with a needle the nervus splanchnicus of the left side, at the inner border of the supra-renal capsule. (In the dog the experiment did not succeed.) Now, since the nervus splanchnicus is the medium of communication between the sympathetic nerve and the cœliac ganglion, while the cœliac ganglion, again, is connected with the spinal nerves, and through them with the spinal cord; it follows, that irritation of the splanchnic nerve may be communicated either immediately; or through the medium of the spinal cord, to the nerves of the abdominal muscles. This observation, in my opinion, renders M. Magendie's theory of the action of emetic medicines very improbable. He supposes that emetics introduced into the stomach are first taken up into the circulation, and thence affect the different organs concerned in the act of vomiting, in the same way as tartar emetic injected into the veins in other parts. But the fact that the splanchnic nerve has the power of exciting contractions of the abdominal muscles, is alone almost sufficient to prove that the vomiting produced by substances taken into the stomach owes its production to the local irritation being propagated through the nerves, and when it is produced by mechanical irritation of the stomach or intestines, by inflammation of the stomach or intestines, or by mechanical irritation of the pharynx, or more correctly the fauces, (*See Dr. Marshall Hall's Mem. on the Nervous System*, p. 97,) it can be explained in no other manner.*

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* In Lund's work (Vivisectionem, &c.) will be found experiments on the subject by Portal, Bourdon, Beclard, and Merat, whose conclusions were opposed to Magendie's opinion; and others, by Rostan, Piedagnel, and Goudret, which were favourable to his view. But none of them are very decisive.

It being very probable, then, that emetics introduced into the stomach excite the movements of vomiting through the medium of nervous communication, the question arises, whether the irritation in such cases is communicated to the brain by the vagus nerve especially, or to the brain and spinal cord by the splanchnic and sympathetic nerves, the auxiliary motions in the act of vomiting being in either case excited by the influence transmitted to the diaphragm and abdominal muscles from the brain and spinal cord through the medium of the spinal nerves. The experiment already mentioned, which shows that the splanchnic nerve has the power of exciting contractions of the abdominal muscles, is a proof that that nerve has a share in the propagation of the irritation. The fact that vomiting is produced by irritation of the pharynx, which is principally supplied by branches of the vagus, proves, on the other hand, that the vagus is implicated in it. It is therefore certainly probable that both vagus and splanchnic nerve act simultaneously in transmitting the irritation when emetic agents act on the stomach and intestine.

The vomiting which is excited by division or ligature of the nervus vagus (*Mayer, in Tiedemann' Zeitschrift*, iii. 62,) is to be explained in the same way. The irritation arising from the ligature of the nerve, and even from the contusion which attends its division, is communicated to the brain; and the inflammation of the ends of the nerve, which necessarily ensues, produces the same impression on the brain, through the medium of the portion of nerve still connected with it, as is produced by irritation of the extremities of the nerves in inflammation of the stomach itself: the same result—vomiting—follows in both cases. The division of other nerves, likewise,—for instance, of the optic nerve, in extirpation of the eye,—sometimes excites vomiting. The observation, that whatever be the dose of an emetic or a purgative given to dogs on which a section of the nervi vagi has been made, no operation follows, is adduced by Brachet (*Recherches sur les fonctions du Système Ganglionaire*) as an argument for the nervus vagus having a share in transmitting to the brain the irritation of the stomach, which excites vomiting. The observation itself, however, is opposed to the fact that vomiting ensues spontaneously in dogs after the division of the vagus.

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* See Magendie's Mémoire concernant l'influence de l'émetique, etc. Nouv. Bull. de la Soc. Philom. t. iii. p. 360.

When vomiting arises from an affection of the brain itself, the irritation is communicated in part directly to the stomach, and in part to the spinal nerves and to the diaphragm and abdominal muscles, in consequence of the spinal marrow being likewise affected. The usual opinion is that the irritation being excited in the vagus nerve by the cerebral affection, that nerve excites contractions of the stomach: but this it is difficult to believe; for, distinct as are the contractions of the œsophagus which may be excited by irritation of the nervus vagus mechanically or by galvanism, I have never succeeded in producing even a single distinct contraction of the stomach by that means, although I have made repeated experiments with that view on rabbits, and carnivorous and granivorous birds, and have employed the strongest mechanical irritation, and even a very powerful galvanic pile, the vagus being in the last case insulated. Even the muscular gizzard of birds cannot be made to contract in the slightest degree. M. Magendie and Mr. Mayo have made similar observations. The motions of the stomach, like those of the intestines, appear to be wholly dependent on the sympathetic nerve. The peristaltic motions of both continue when they are removed from their connections in the body; Wepfer observed this of the stomach, and others have noticed it with regard to the intestines.

The mode of action of emetics introduced into the circulation still remains to be considered. There is no very evident explanation for it, or rather we do not possess sufficient data to enable us to determine the question in a decided manner. It is in fact a matter of indifference whether an irritant is applied to the mere surface of an organ, or acts more directly on the parenchyma, through the medium of the blood which traverses it. Thus arsenic excites inflammation of the stomach, even when applied primarily to other parts of the body. Hence it appears probable that the tartar emetic introduced into the blood acts on the organs which participate in the act of vomiting through the medium of their blood-vessels. But it is still a matter of doubt whether its more important action is upon the organs from which the nervous energy for the movements of vomiting are derived, or upon the organs of motion themselves.

6. *Motions of the intestines.*—The *vermicular*, or *peristaltic movements* of the intestines, like those of the stomach, appear to be generally very feeble during life; it is only in a nervous state of the system, in dyspepsia, in spasmodic action of their muscular coats, and particularly in intestinal irritation or diarrhœa, that the action of the intestines becomes more rapid. When an animal is opened

during life, the peristaltic motions are at first scarcely perceptible, but by exposure to the air they are soon increased in force, and become extremely energetic; the intestines rise and fall, and propel onwards their contents, generally in the direction of the rectum. If a stimulus, whether mechanical or chemical, or the galvanic influence, is applied to any part of the intestines, contraction takes place, and the intestine by degrees becomes very narrow at that point, the greatest degree of contraction not ensuing until after the action of the stimulus has ceased; the subsequent relaxation is likewise gradual. A strong galvanic shock applied to the splanchnic nerve insulated on a plate of glass, or to the cœliac ganglion, gives rise to a generally increased activity of the peristaltic movements, while neither division of the vagus nor of the sympathetic nerve puts a stop to them: they continue even after the intestine is removed from the body.

The *sphincter ani* is always in a contracted state except at the time of the evacuation of the fæces. It seems to have, in common with all muscles, a slight degree of the power of constant contraction, which does not become sensible until the antagonising muscles are divided. But the accumulation of the fæces in the rectum, and the irritation produced thereby, cause a stronger contraction of the sphincter, which continues till it is overcome by the increasing pressure of the excrement. The sphincter may by an effort of the will be made to contract more strongly, but it cannot be made to relax. The contraction of the sphincter ani is in some rare cases overcome, and the fæces, when of soft consistence, are expelled by the mere involuntary contraction of the rectum, without the aid of the abdominal muscles. Legallois and Beclard, (*Bull. de la Fac. et de la Soc. de Méd.* 1813, N. 10,) indeed, state that they have seen this occur after the abdominal muscles had been removed. Usually, however, the diminution of the capacity of the abdomen by the contraction of the diaphragm and abdominal muscles with the voluntary action of the levator ani, are necessary to effect the expulsion of the fæces. But all these voluntary muscles contract involuntarily and spasmodically, as in vomiting, when the irritation excited by the fæces has continued for a long time, and is become very great.

The *muscular action of the rectum* may be paralysed in consequence of injuries or disease of the spinal marrow (and brain), and this may give rise to incontinence or permanent retention of the fæces, according as the paralysis affects more particularly the sphincter ani or the rectum and abdominal muscles. Division of the phrenic nerves, and the consequent paralysis of the diaphragm, are said by Krimer not to prevent the expulsion of the fæces, although such is the effect of dividing the abdominal muscles, or the spinal cord between the fifth and sixth vertebræ, in dogs. Dr. Marshall Hall (*Memoirs on the Nervous System*, p. 13,) has shown that the sphincter ani is under the influence of the lower extremity of the spinal cord, and that when this part of the nervous centres is destroyed, the sphincter becomes flaccid, and does not contract on the application of a stimulus.

CHAPTER IV.

OF THE SECRETIONS POURED INTO THE DIGESTIVE CANAL.

1. *Saliva.*—There seems to be a secretion of saliva in almost all animals, with the exception of the Cetacea and fishes. Whether the secretion of the poison glands with which some serpents[*] (and Arachnida also) are provided, contributes to the solution of the food, is not known. An analogy has been supposed to exist between such secretions and the saliva of rabid animals, but there is no foundation for the comparison; since the poisonous property of the saliva in rabies is not an essential quality of it, and it appears from the experiments of Hertwig, at the veterinary school of Berlin, that other secretions of rabid animals, and at all events their blood, are capable of producing the disease by inoculation. This does away likewise with the inference deduced from a circumstance which has been asserted to occur, namely, the assumption of a poisonous quality by the saliva under the influence of passion. The material changes in the body consequent on violent affections of the mind are general, implicating several secretions simultaneously; they have been particularly observed in the milk. Moreover, it has not been proved that the bites of enraged animals differ from common lacerated wounds.

The *quantity of the salivary secretion* has been made the subject of observation by Dr. C. G. Mitscherlich in a man who had fistula of the stenonian duct. He found that when the muscles concerned in mastication, and the tongue, were completely at rest, and the nerves were subject to no unusual stimulus, the secretion ceased, but that it was excited by the opposite circumstances. The quantity of the saliva secreted by one parotid in a healthy man during twenty-four hours was from sixty-five to ninety-five grammes (about from two to three ounces troy); and the saliva collected from the mouth during the same period, and derived from the five other salivary glands, amounted to six times more than that from the one parotid.[†] In the same space of time Schultz collected from the stenonian duct of a horse fifty-five ounces seven drams of saliva, of which twelve ounces were secreted during the first feeding-time, which occupied two hours; and ten ounces nine drams during the three hours which elapsed between the first and second feed. (*Schultz, de Aliment. Concoctione. Berol.* 1834.

The *chemical composition of the saliva* has been examined in an admirable manner by Berzelius, by Gmelin, and by Mitscherlich.

The saliva obtained from the mouth is a viscous fluid consisting of a mixture of saliva and mucus. Berzelius, having collected it in a deep narrow vessel, found that it separated into an upper transparent and colourless fluid, and a lower portion, which was a mixture of the same fluid and a white opaque matter. By previously mixing the saliva with water, and agitating them together, Berzelius was enabled to separate more completely the mucus, which sank to the bottom of the vessel.

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[*] For an account of the effects of the bite of poisonous serpents, consult Fontana über das Viperngift; Berlin, 1787, p. 15: Traité sur le Venin de la Vipère; and Rengger, in Meckel's Archiv. 1829.

[†] Mitscherlich, über den Speichel des Menschen. Rust's Mag. 1838.

Saliva varies as to acid or alkaline reaction. Tiedemann and Gmelin found it to be generally slightly alkaline, sometimes neutral, never acid. Schultz states that it is acid in the adult when it has been retained long in the mouth, but that it is always alkaline in children. The saliva of dogs and sheep collected from the parotid duct, was found by Gmelin to be alkaline. C. H. Schultz also states as the result of his observation, that the saliva of the human subject is generally alkaline, one drachm requiring one drop of acetic acid to neutralise it. He found the saliva of the horse also alkaline: and he asserts that, after the saliva had been neutralised, it gradually recovered its alkaline property. Dr. Mitscherlich found the saliva which he collected from a fistula of the parotid duct to be alkaline during a meal, but acid at other times. The alkalescence of the saliva is stated by Schultz to be dependent on the presence of ammonia. Mitscherlich, on the contrary, asserts that fresh saliva evolves no ammonia when heated, and that its alkaline property is owing to its containing a fixed alkali.

The observations of Sebastian and Van Setten, (*Diss. de saliva ejusque vi et utilitate. Groning.* 1837–8,) and of Mr. Laycock, (*Med. Gaz. Oct.* 1837) seem to show that the reaction of the saliva may vary from acid to alkaline under the influence of many very trifling circumstances. It appears to be very seldom quite neutral. Seven observations on the reactions of the saliva, which the translator had recently the opportunity of instituting in a case of fistula of the parotid duct, tended to confirm Mitscherlich's statement, that the saliva becomes alkaline when food is taken, but is acid at other times.

The specific weight of the fresh saliva obtained by Mitscherlich was from 1.0061 to 1.0088; that of the horse's saliva, examined by Schultz, was 1.0125.

Saliva contains globules in very small number; they have been observed by Leeuwenhoeck, Weber, Tiedemann, and myself; they are transparent, and, according to Weber, are larger than the red particles of the blood.

The solid particles floating in the saliva are in part scales of epithelium separated from the surface of the mucous membrane of the mouth; in part mucous globules poured out by the mucous follicles; and in part probably the nucleated globules, which, according to Henle, are formed as secondary cells within the terminal vesicles of the salivary secreting canals.

Berzelius estimates the amount of solid matter which saliva holds in solution, at about 1 per cent. The mass which remains when saliva is evaporated, is transparent; alcohol extracts from it a small quantity of osmazome, with some chloride of sodium and potassium, and lactate of an alkali. The matter which is not dissolved by the alcohol, is slightly alkaline, and contains soda. The residue, when this soda is removed, is found to consist of mucus, which constitutes ⅓d, and a peculiar substance called salivary matter, which has been rather differently described by Berzelius, Mitscherlich, and Tiedemann and Gmelin. From the mucus which remains after the extraction of the salivary matter by means of cold water, Berzelius obtained a large quantity of phosphate of lime, from which probably the tartar of the teeth is formed, since it consists of phosphate of lime.

The following are the results of Tiedemann's and Gmelin's analysis. By evaporating the saliva of the human subject, they obtained from 1·14 to 1·19 per cent. of solid residue; this yielded 0·25 part of ashes, of which 0·203 were soluble in water, and 0·047 were earthy phosphates. 100 parts of the residue of diluted saliva gave:—

A substance soluble in alcohol, and insoluble in water, (fat containing phosphorus,)	31·25
Matters soluble both in alcohol and water, (osmazome, chloride of potassium, lactate of potash, and sulpho-cyanuret of potassium,) . .	
Animal matter soluble in boiling alcohol, but precipitated during cooling, with sulphate of potash, and some chloride of potassium, . .	1·25
Matters soluble in water only, (salivary matter, with abundant phosphate and some sulphate of an alkali and chloride of potassium,) . .	20·00
Matters soluble neither in water nor in alcohol, (mucus, perhaps some albumen, with alkaline carbonate and phosphate,) . . .	40·00
	92·50

The saline ingredients of the saliva are, according to Dr. Mitscherlich:—

Chloride of potassium, ...	0·18	per cent.
Potash, (combined with lactic acid,) . . .	0·094	
Soda, (combined with lactic acid,) . . .	0·024	
Lactic acid, ...		
Soda, (probably combined with mucus,) . .	0·164	
Phosphate of lime, ...	0·017	
Silicic earth, ...	0·015	

The proximate organic principles obtained from the saliva by Mitscherlich are similar to those which Berzelius enumerates.

The matter which Tiedemann and Gmelin have shown to be *sulphocyanogen* was first discovered to be *an ingredient in the saliva* by Treviranus, (*Biologie*, iv. 565:) he found that saliva became of a deep red colour when mixed with a neutral solution of a salt of the peroxide of iron. This was confirmed by Tiedemann and Gmelin; but I must remark that, in my experiments, whatever per-salt of iron I might add, the colour produced was only rust-red, not purple. Dr. Ure (*Journal of Science, Literature, and Arts*, N. S. vii. p. 60,) regards the existence of sulpho-cyanogen in the saliva as established beyond all question by his experiments(?).

Van Setten* regards the presence of sulpho-cyanic acid in the saliva as almost certain, since the watery solution of the alcoholic extract distilled with phosphoric acid yielded a fluid which with chloride or iron produced the red colour of sulpho-cyanate of iron. He may have mistaken the colour; but he states that by decomposing saliva with which a solution of baryta was mixed, he obtained sulphate of baryta, which certainly seems to prove that the saliva contains sulphur.

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* Diss. de Saliva ejusque Vi et Utilitate; and Müller's Archiv. 1838, p. clxiv.

Of the animal matters of the human saliva,—namely, salivary matter, mucus, and osmazome,—the first was found by Tiedemann and Gmelin to be almost wholly wanting in the saliva of the sheep, the last in that of the dog.

The *tartar which collects on the human teeth* has been analysed by Berzelius, who states its composition to be as follows:—

Salivary matter, ...	1·0
Salivary mucus, ...	12·5
Earthy phosphates, ...	79·0
Animal matter dissolved by muriatic acid, . .	7·5
	100·0

The *saliva of insects* has not been accurately examined; it appeared to Rengger[*] to be alkaline.

2. *The gastric juice.*—The descriptions given of the gastric juice by the earlier writers, who made it the subject of examination, were quite contradictory. Spallanzani, who sought to prove that the gastric secretion is a solvent of the articles of food out of the body as well as in the stomach, asserted that it is perfectly neutral; while Montègre (*Sur la Digestion.* Paris, 1804,) found it to be generally acid, although he denied its solvent power. Helm (*Zwei Krankengeschichten.* Wien, 1803,) detected no acidity in the gastric fluid obtained from a patient who had a fistulous opening communicating with the stomach; Viridet, Carminati, Brugnatelli, and Werner, on the contrary, observed its acid property. The discrepancy of these statements was, however, in some measure explained by the experiments of Carminati, (*über die Natur des Magensaftes.* Wien, 1785,) who found that the gastric fluid obtained from carnivorous animals while fasting, was never acid, but became distinctly so as soon as food was taken. He remarked that the gastric juice of herbivorous animals also was acid, but detected no remarkable acidity in that of man and animals of mixed food. Tiedemann and Gmelin have finally determined the question. They ascertained that the fluid in the stomach of horses and dogs, while the animals were fasting, was nearly neutral, or only very slightly acid; but that it acquired a marked degree of acidity as soon as mechanical irritants, such as stones or peppercorns, were introduced into the stomach. Leuret and Lassaigne have made the same observation. It was the secretion of the stomach only that was acid in these cases; no acidity could be detected in the œsophagus.

The gastric juice has hitherto been examined by no one in such large quantity, in such a pure state, and so frequently, as by Dr. Beaumont, (*op. cit.*) who, during several years, carried on a long series of experiments, relative to digestion, on the young man, (Alexis Martin,) in whom a large opening communicating with the stomach remained after a gun-shot wound. Dr. Beaumont confirms the statement, that the stomach when empty secretes no gastric juice, and that the fluid which moistens its surface in that state is not acid, but becomes so as soon as food is taken. Schultz, who wholly denies the existence of a gastric juice, and attributes the acid reaction of the chyme to decomposition of the food itself, could not but perceive an objection to his theory in the fact observed by Tiedemann and Gmelin, that the secretion of gastric juice can be excited in animals when the stomach contains no food, by the introduction of mechanical stimuli, such as stones; and he explains the acid property of the fluid in the stomach in these cases by supposing it to be the remains of acid chyme. The numerous experiments of Dr. Beaumont, however, render it impossible for the existence of a gastric fluid to be any longer doubted. Having ascertained that the stomach was empty, and that its coats evinced the presence of no free acid, he irritated it mechanically by introducing through the wound a caoutchouc tube, or the bulb of a thermometer, and observed that, however often the experiment was repeated, a pretty copious acid fluid was each time poured out; he was frequently able to obtain by this method nearly an ounce of the secretion.

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[*] Physiol. Untersuch. über die thierische Haushaltung der Insecten. Tüb. 1817.

The degree of acidity, which is an interesting point, has been investigated by Schultz; and from the mean of his observations, it appears, that one part of chyme requires, for its neutralisation, $\frac{1}{100}$ of carbonate of potash.

The source of the gastric fluid seems to be the very simple follicles of the mucous membrane of the stomach, at least in those animals which have no special glands for its secretion. The structure of the mucous membrane of the human stomach has been already described. Tiedemann and Gmelin found that the property of coagulating milk was possessed, not only by the pyloric, but also by the cardiac portion of the stomach. Dr. Beaumont states expressly, that the secretion appeared to him to be poured into the stomach of his patient by minute lucid points, or very fine papillæ. In several animals there are distinct gastric glands; we may instance the great gastric gland of the beaver, which most probably secretes a fluid destined for the solution of barks of trees; there is a similar gland in the cardiac portion of the stomach of the Myoxus; and with these we may also class the *proventriculus* of birds, between the mucous and muscular coats of which there is a complete stratum of follicular cæca-like glands opening by separate mouths.*

Chemical analysis.—Dr. Prout (*Philos. Transact.* 1824, p. 1,) was the first chemist who instituted an accurate analysis of the gastric secretion. He showed that the gastric secretion of the rabbit, hare, horse, calf, and dog, contains free muriatic acid; and both Prout and Children (*Annals of Philosophy.* July, 1824,) detected the same acid in the fluid raised from the stomach by dyspeptic patients. Prevost and Le Royer (*Froriep's Notiz.* ix. p. 194,) confirmed Prout's observations as to the presence of muriatic acid in the gastric juice. Leuret and Lassaigne, it is true, denied it, but Prout refuted their objections.

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* Sir E. Home's Lectures on Comparative Anatomy. t. ii.; and J. Müller, de Penit. Gland. Struct.

Tiedemann and Gmelin afterwards detected three acids in the gastric juice. 1. *Muriatic acid,* in the gastric acid of the horse and dog. 2. *Acetic acid,* in the gastric juice of the same animals. Chevreul has likewise found lactic acid, which is nearly allied to acetic acid, in the fluid vomited by a person fasting; and Dr. Graves has found it in the matter vomited by a dyspeptic patient. 3. *Butyric acid* was twice detected by the German physiologists in the stomach of the horse.

Schultz distilled the chyme with water, and found that in many animals a part of the acid or the whole of it passed over with the distilled fluid. He states, as the results of his experiments, that the acid of the chyme is free acetic acid; and that the muriatic acid is not free, but combined with potash.

The third and fourth stomachs only of ruminating animals are acid, and the acidity is most marked in the fourth. The fluid which collects in the first and second stomachs during fasting, is said by Prevost and Le Royer to contain a large quantity of alkaline carbonate; and Tiedemann and Gmelin have confirmed this observation.

Dr. Beaumont describes the secretion of the human stomach, which he obtained by irritating the stomach of St. Martin, as follows: —It is a clear transparent fluid, without smell, slightly saltish, and very perceptibly acid. Its taste resembles that of thin mucilage slightly acidulated with muriatic acid. It is readily diffusible in water, wine, or spirits, and effervesces slightly with alkalies; it precipitates albumen; itself undergoes putrefaction with difficulty, and checks its progress in other animal substances. Mixed with saliva, it strikes a blue colour and becomes frothy. Dr. Beaumont submitted a certain quantity for analysis to Professor Dunglison, who found it to contain free muriatic acid, acetic acids, phosphates and muriates of potash, soda, magnesia, and lime, and an animal matter which was soluble in cold, but insoluble in hot water. He sent another portion of it to Dr. Silliman, whose analysis, however, loses its value, on account of the fluid having been kept several months before it was examined. It was still acid, although a pellicle had formed on it; it contained muriatic acid, a trace of sulphuric acid, and Dr. Silliman suspected the presence of some phosphoric acid.

The fluid of the crop of birds is, according to Tiedemann and Gmelin, usually acid. The secretion of the *proventriculus* contains a free acid, even at the time that digestion is not going on. The gastric secretion of birds coagulates milk. The acidity is owing to the presence of muriatic, and probably of acetic acid likewise. It has been suggested by Treviranus, (*Biologie,* iv. p. 362,) that the gastric secretion of birds probably contains fluoric acid, since Brugnatelli (*Crell's Annalen,* 1787, i. p. 230,) has observed that rock crystal and agate, enclosed in tubes, and introduced into the stomach of hens and turkeys, were, at the end of ten days, distinctly acted on, and had lost ten or twelve grains of their weight; and Treviranus himself witnessed a similar action on a porcelain capsule, in which some chyme from the stomach of hens had been digested. Tiedemann and Gmelin, (*loc. cit.* part ii.) with a view to determine the question, digested some of the gastric secretion of ducks in a platina crucible, which was covered with a glass plate, on which some device had been drawn through wax; but at the expiration of twenty-four hours, no trace of any erosion of the glass was perceptible. They do not, however, hence infer that the gastric juice of birds does not contain fluoric acid; for fluoride of calcium is certainly met with in several animal tissues, as in the bones and in the urine.

The gastric secretion of reptiles is generally acid; in the stomach of fishes, also, particularly when it contains food, there is a free acid. Other reasons render it probable that, in both these classes, the gastric secretion contains muriatic and acetic acids.

Leuret and Lassaigne* believe that the free acid of the stomach in all the four vertebrate classes is lactic acid. Eberle, (*Physiologie der Verdauung*. Würzburg, 1834,) however, has discovered that this acid is not the solvent principle of the gastric juice; but that the mucus of the stomach, (like all mucus, he says,) has the property, when acidulated, of inducing decomposition and subsequent solution of the food. And accordingly we find that with acidulated mucus of the stomach, artificial digestion of the food can be accomplished, even out of the body.† Eberle was incorrect in stating that other mucus than that of the gastric mucous membrane is, when acidulated, adequate to the solution of the food; and hence we may conclude that the solvent principle cannot be the mucus itself, but must be a peculiar substance contained in the mucus of the stomach. It is the same substance which causes the coagulation of the milk of the stomach. Most of what we know of the digestive principle, "pepsin," we owe to Schwann.‡ No method is at present known by which it may be obtained in a perfectly pure state. A further account of it will be given in the chapter on the digestive process.

3. *The bile.*—The bile is a secretion so generally met with in the animal kingdom, and so important in relation to the digestive process, that it would be in the highest degree interesting to know whether even in the lowest animals it is ever wholly wanting. We might regard, and some indeed have regarded, as the first form of the liver among the vermes, those sac-like dilatations or cæcal appendages of the intestinal canal, which are seen in the medicinal leech in their simplest form,—that of lateral dilatations,—in the Aphrodita as long and narrow cæca, but which in other worms are ramified cæca; while in the Planariæ and Distomata, lastly, they assume the form of a completely ramified intestinal tube which has no anal opening. The cæcal appendages of the stomach of the

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* Recherches Physiol. pour servir a l'Hist. de la Digestion. Paris, 1825.

† See J. Müller and Schwann, über die künstliche Verdauung des geronnenen Eiweisses. Müller's Archiv. 1836, p. 66.

‡ Uber das Wesen des Verdauungs-prozesses. Müller's Archiv. 1836, p. 90.

Asterias family, which likewise has no anal aperture, might be regarded as analogous secreting organs; but the nature of their secretion cannot be ascertained, nor indeed is it known that they secrete at all.

The long cæcal convoluted tubes which open into the intestinal canal of insects, generally in pairs, at a variable distance from the mouth and anus, but always below the dilated part of the canal which is supposed to be the stomach, have been called biliary vessels. They do not, however, contain bile; but according to Chevreul* and Audouin, (*L'Institut*, 135,) uric acid: besides, they secrete very actively during the development of the pupa, when no food is digested. They are, therefore, evidently excreting organs,—*vasa urinaria.* They open into the canal below the part where the chyle is formed, and in larvæ often but a short distance from the anus. I am, on the other hand, inclined with Meckel (*Meckel's Archiv.* 1826,) to regard as true biliary organs those cæca which are met with in many insects opening into the intestinal canal higher up, either into the membranous stomach which succeeds the gizzard in the carnivorous Coleoptera, or into the part of the canal just below the gizzard, as in many Orthoptera, &c. In the Arachnida,—for example, in the scorpion,—there are true biliary vessels opening into the upper part of the intestine, and other Malpighian or excreting tubes at the lower part.†

Is the bile secreted from arterial or venous blood?—The liver of vertebrate animals receives two kinds of blood—arterial and venous; the sources whence the venous blood carried to the liver by the vena portæ is derived, have been already mentioned. The distribution of the minute branches of the blood-vessels in the liver to be hereafter described, and the arguments then stated, will render improbable Mr. Kiernan's opinion, that the branches of the hepatic artery do not contribute to the formation of one and the same general capillary network with the portal and hepatic veins, but are distributed solely to the coats of the ducts, gall-bladder, and the other blood-vessels; the blood carried by the artery after nourishing these parts being, according to his view, poured into branches of the portal vein. Mr. Kiernan believes the bile to be secreted from venous blood, while the arterial blood serves for the nourishment of the tissues of which the liver is constituted, and for the secretion of the mucus in the gall-bladder and in the ducts by the follicles which he has discovered in them.

But the possibility of bile being secreted from arterial blood is demonstrated by the cases in which the vena portæ enters the vena cava directly instead of being distributed through the liver. Mr. Abernethy (*Philos. Trans.* 1793,) observed this anomalous structure in a male child ten months old; and Mr. Lawrence (*Medico-chirurgical Transact.* v. p. 174,) has detailed a case in which the same malformation existed in a child several years of age. In Mr. Abernethy's case, however, the umbilical vein was still pervious, and branched out in the substance of the liver: it is possible, therefore, as Mr. Kiernan remarks, that the arterial blood, after having nourished the liver, was poured into the branches of the umbilical vein, just as it is in the normal condition, according to his opinion, poured into branches of the portal vein: and the secretion of bile therefore might still have been derived from venous blood. (*Kiernan, Philos. Transact.* 1833, part ii.

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* Strauss-Duerckheim's Considerations Générales sur l'Anatomie des Animaux Artic. Paris, 1828, 4, 251.

† See J. Müller de Gland. Penit. Struct. Tab. viii. fig. 8.

M. Simon (*Nouv. Bull. des Sc. par la Soc. Philomat.* 1825.) and Mr. B. Phillips (*London Medical Gazette*, April 13, 1833.) have inferred, from experiments which they performed, that the bile is secreted from the blood of the portal vein. But Mr. Phillips found that after the vena portæ had been tied, the secretion of the bile still continued, though in diminished quantity; and he concludes, therefore, that it is formed both from arterial and venous blood. He perceived no change in the biliary secretion when the hepatic artery was tied.

With respect to the *quantity of bile*, we have some observations by Schultz. In oxen which had not recently taken food, he found from twelve to sixteen ounces of bile in the gall-bladder; after digestion, it contained from two to four ounces. In a large dog, the gall-bladder contained, after a fast, five drachms; in a middle-sized dog, just after digestion had been performed, it contained only two drachms and seventeen grains.

Properties of the bile.—The bile is a fluid of a green colour, bitter taste, and nauseous smell. The bile which flows from the liver is of a lighter colour: that obtained from the gall-bladder is less fluid and greener, on account of the more fluid part having been absorbed; and it is more viscid, owing to its containing mucus. It contains whitish or gray particles, which in the frog I found irregular in form and size. They were, in the mean, five times smaller than the red particles of the animal's blood, others were more minute. According to Henle, these are particles of epithelium, the more elongated bodies being derived from the surface of the excretory duct; those which more nearly approach the globular form, from the biliary secreting canals. The matter which gives to the bile its green colour is in solution. Bile is stated by Schultz to be, when fresh, always alkaline; when of thick consistence, one ounce required one drachm of acetic acid for its neutralisation; when the bile was more fluid, the same quantity was neutralised by ⅓ or ½ drachm of the acid. Schultz found the specific weight of the bile of the ox to be from 1·026 to 1·030. It does not coagulate at the boiling temperature, and does not dissolve oils. Werner asserts that bile added to the blood out of the body prevents its coagulation, and causes the red colouring matter to become dissolved in the serum; the latter statement, however, is incorrect.

The results of Berzelius's analysis of the *bile of the ox*, in 1807, are as follows:—

Of bile evaporated to the consistence of an extract, alcohol dissolves all but a yellowish grey substance, which resembles in every respect the mucus of the gall-bladder. The alcoholic solution being

2. Cholesterine; the component of the gall-stones, shown to be an ingredient of fresh bile by Chevreul, and obtained from it by means of ether. It is found in other parts of the body,—according to Boudet, in the blood; but it is generally a morbid product; thus it is found in the fluid of local dropsies, such as hydrocele, and in medullary fungus.

3. Elaic acid.

4. Stearic acid.

5. Cholic acid, a new substance, which crystallises in fine acicular crystals of a sharp sweet taste, and is soluble in alcohol. It contains nitrogen.

6. Biliary resin, which, according to Gmelin, contains no nitrogen.

7. Taurine, a new substance, which crystallises in large colourless, transparent, irregular, six-sided prisms, with four or six-sided summits, is soluble in water, and contains a small quantity of nitrogen.

8. Picromel. Thenard's picromel is a thick fluid, like turpentine. Gmelin's picromel is opaque, consists of crystalline granules, and contains a large proportion of nitrogen. Gmelin believes that the substance which Thenard called picromel was a compound of that substance with resin.

9. Colouring matter of the bile; a substance containing nitrogen, which is recognised even when it is present in other fluids, such as the blood and urine in jaundice, by the addition of an equal quantity of nitric acid, striking a greenish, then a dark green, a dirty red, and, lastly, a brown colour.

10. Osmazome. 11. A substance which, when heated, gave out a urinous odour. 12. A substance like vegetable gluten. 13. Albumen. 14. Mucus of the gall-bladder. 15. Casein. 16. Salivary matter. 17. Bicarbonate of soda. 18. Carbonate of ammonia. 19. Acetate of soda. 20—26. Salts of elaic, stearic, cholic, sulphuric, and phosphoric acids, with potash and soda, chloride of sodium and phosphate of lime.

In *human bile* Gmelin found cholesterine, biliary resin, picromel, and elaic acid. Chevreul, Chevalier, and Lassaigne have also detected picromel in human bile; and Orfila, Laugier, and Caventou obtained it from human gall-stones. Besides the substances just mentioned, Frommherz and Gugert (*Schweigger's Journal*, 50, 68,) have found in human bile colouring matter, salivary matter, casein, osmazome, salts of elaic, cholic, stearic, carbonic, phosphoric and sulphuric acids, with soda and a little potash, and phosphate, sulphate, and carbonate of lime.

Berzelius suggests that the bile, in the natural state, is perhaps a more simple fluid than would appear from the analytic results obtained by chemists, and that it very probably contains the albuminous matters of the blood, certainly in an altered state, but combined with the same salts as in the blood itself; he supposes, however, that the substance which these albuminous matters compose, has so great a tendency to undergo changes in its composition, that the action of different re-agents upon it converts it into different compounds, varying according to the processes employed to extract them, exactly as oils and fats are converted into sugar and fatty acids by the action of the oxides of lead and zinc. M. Demarcay (*Comptes Rendus*, 1838 t. i. p. 199,) has recently revived the old notion that the bile is a substance of a saponaceous nature. It is, according to his analysis, a compound of soda with an oily organic acid (choléic acid), which is obtained by the action of dilute hydrochloric, sulphuric, or phosphoric acid on bile of the ox. By boiling this choléic acid with dilute hydrochloric acid, M. Demarcay produces the taurine of Gmelin, and another acid, which he names the choloidic; while the alkalies decompose his choléic acid into ammonia and the cholic acid of Tiedemann and Gmelin. The main facts stated by M. Demarcay are admitted as correct by MM. Pelouze and Dumas.*

Schultz considers the coagulum produced in bile by the addition of alcohol to be, not albumen, but a substance similar to salivary matter; since bile does not coagulate under the influence of heat. The alcoholic solution of bile evaporated to dryness had still an alkaline reaction; but Schultz differs from most chemists in believing this alkalinity to be owing to the presence, neither of carbonates of the fixed alkalies, nor of ammonia,—for the fluid obtained by distillation has, he says, no alkalescence,—but of an organic alkali similar to the vegetable alkaloids, which he supposes to exist in the bile in combination with elaic acid. The coagulum produced by acids likewise he regards, not as albumen, but as a precipitate of the alkaloid with the acid. The substance which he obtained by the action of acetic acid, however, was evidently the mucus of the gall-bladder, which is, according to Berzelius, precipitated from the bile by acetic acid; and Schultz himself remarks that the bile still retained in solution a bitter, or sweetish bitter substance.†

Bile of serpents and fishes.—The bile of serpents was found by Berzelius to contain a peculiar substance, which is precipitated neither by acids nor by alkalies, and which differs from the "biliary matter" of warm-blooded animals in not being decomposed into picromel and biliary resin by acetate of lead.

The *bile of Crustacea and Mollusca* has not been examined.

Discharge of the bile.—The gall-bladder of vertebrate animals is developed as a diverticulum or protrusion from the efferent duct. (*See J. Müller, de Gland. Penit. Struct.*) In man and many Mammalia the flow of the bile into the intestine can be arrested either by the intestinal opening of the ductus choledochus being closed, or by prolonged contraction of the duct itself; and the bile, poured by the hepatic duct into the ductus choledochus communis, is thus made to regurgitate into the cystic duct and gall-bladder. It is more particularly during fasting that this takes place. In many animals, however, the gall-bladder receives bile by other hepatic ducts, which enter at its neck or at its fundus, and are called "ductus hepatico-cystici:" they do not exist in the human subject; but in birds they are the only means by which bile can reach the gall-bladder, for the hepatic duct opens into the duodenum without joining the cystic duct. In reptiles the bile is carried into the gall-bladder by branches of the hepatic duct. In fishes all the hepatic ducts coming from the different lobes enter the gall-bladder or its duct. In the ox, which is said by Rudolphi (*Physiologie,* ii pt. ii. p. 153.) to be the only one of the domestic animals in which the hepatico-cystic ducts exist, they are from eight to ten in number.

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* Report on the paper of M. Demarcay, Comptes Rendus, 1838, t. ii. p. 425.

† The account of the chemical composition of the bile has been abridged by the translator. For the chemical details of the different analyses he refers to the work of Berzelius on organic chemistry.

Many animals—among Mammalia, birds, and fishes—have no gall-bladder. (See *Cuvier's Leçons d'Anatomie Comparée.*) There seems to be no general law for its presence or absence, although the species in which it is wanting are for the most part herbivorous, and are animals in which digestion is constantly going on; yet very many vegetable feeders are provided with a gall-bladder. When the gall-bladder is wanting, the duct is frequently very much dilated; such is the case, for example, in the horse.

4. *The pancreatic secretion.*—We may almost regard the pancreas as an organ belonging exclusively to the vertebrate classes of animals; the two light-red lobulated glands attached to the biliary ducts in the Loligo sagittata, pointed out by Dr. Grant (*Froriep's Notiz.* xi. 182,) to be analogous to a pancreas, are the only exception. The pancreas is not constant in the class of fishes; it is in some entirely wanting; in others its place is supplied by cæca, called appendices pyloricæ, which vary in number and arrangement, becoming more and more divided as they are traced through different genera; until in the sharks and rays they are replaced by a solid gland.

The secretion of the pyloric cæca of fishes is adhesive, and according to the observations of Swammerdam, and of Tiedemann and Gmelin, is not acid or only very slightly so. The pancreas has been wholly, or in greater part, destroyed in dogs, without their digestion or general health suffering. Only in a few instances was greater voracity observed after the operation. (*Autenrieth, Physiol.* ii. 69.)

The examination of the pancreatic secretion of the higher animals has been recently undertaken by Mayer, Magendie and Tiedemann and Gmelin. Mayer (*Meckel's Archiv.* iii. p. 170,) obtained it in some quantity from a vesicular reservoir in which it had collected in the cat; he found it alkaline and transparent. M. Magendie* describes the pancreatic secretion of the dog as a yellowish fluid, without smell, of a saline taste, alkaline and coagulable by heat, like that of birds. Tiedemann and Gmelin collected the secretion of the pancreas in a large dog by means of a tube introduced through an incision into the duct. A drop issued every six or seven seconds, and nearly ten grammes, (about two drachms and a half,) were obtained in four hours. It was clear, though somewhat opaline, ropy, like white of egg in water, and had a slightly saline taste. They obtained some in the same manner from the sheep and horse. In all three cases the fluid which first flowed was acid; the latter portions only were slightly alkaline in the dog and horse. M. A. Schultz found the pancreatic secretion of the dog, cat, and horse, acid; once only, in the dog, it was neutral. The comparative analysis of the secretion in the dog, sheep and horse, afforded Gmelin the following results:—The pancreatic secretion contains a large quantity of albumen; while no sulphocyanic acid salts, which the saliva is said to contain, can be detected in it. The solid matter which it holds in solution amounts in the dog to 8·72 per cent.; in the sheep, to from four to five per cent. The different solid ingredients are:

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* Physiologie, t. ii. p. 367. Dr. Milligan's translation, fourth edition, p. 461.

1. Osmazome; 2. a matter which is reddened by chlorine, and which is found only in the dog and sheep; 3. a substance resembling casein, combined probably with salivary matter; 4. a large quantity of albumen, amounting to about half of the dry residuum; 5. a very small proportion of free acid, probably acetic acid.

The ashes left after calcination of the dried evaporated secretion amounted in the dog to 8.28 per cent., in the sheep to 29.7 per cent.; it contained the following soluble salts: 1. carbonate of potash, which is probably in the state of acetate in the secretion (found in the dog and sheep); 2. abundance of alkaline muriate; 3. a small quantity of alkaline phosphate (in the dog and sheep); 4. a very small quantity of alkaline sulphate, of which the base was in greater part soda than potash (also in the dog and sheep). The insoluble salts contained in the ashes were small quantities of carbonate and phosphate of lime. A comparison of the pancreatic juice with the saliva, founded on the data furnished by the above excellent analyses of the pancreatic secretion, gives the following results:—The saliva contains mucus and salivary matter; the pancreatic juice, on the other hand, contains an abundance of albumen and casein, no mucus, and little or no real salivary matter: saliva is alkaline; the pancreatic secretion, while fresh, is acid. The saliva of the sheep contains a small quantity of sulphocyanate of an alkali (?); the pancreatic juice, none. The other salts are about the same in both. (*Tiedemann* and *Gmelin*, loc. cit.)

Leuret and Lassaigne obtained three ounces of secretion from the pancreas of a living horse in half an hour. It was clear, had a saline taste, an alkaline reaction, and contained only $\frac{9}{10}$ per cent. of solid constituents, which, after an examination apparently superficial, they concluded to be the same as those of saliva. The statement of their analysis is as follows:—Water, 99·0: animal matter soluble in alcohol, animal matter soluble in water, traces of albumen, mucus, free soda, chloride of sodium, chloride of potassium, and phosphate of lime, 00·9.

The small quantity of secretion which Krause (*Müller's Archiv.* 1837, p. 17,) was able to obtain from the pancreatic duct in the body of a man who was drowned while digesting a full breakfast, and who was examined very soon after death, was colourless and clear, of the consistence of white of egg thinned with water, and neutral, and contained yellowish transparent globules about $\frac{1}{802}$ of a line in diameter. Acetic acid produced in it a whitish cloud and partial coagulation which was increased by moderate heat.

5. *Intestinal secretion: succus entericus vel intestinalis.*—The secretion of the intestines has been examined by Tiedemann and Gmelin in animals which had fasted for some time. In dogs the inner surface of the mucous membrane was found covered with a thin layer of a very consistent, whitish, and somewhat yellowish matter; the intestines contained very little bile. If flint pebbles, or peppercorns, had been previously swallowed, there was a larger quantity of a thin ropy mucus, and more bile. The mucous mass became more consistent towards the lower part of the small intestines, acquired a yellowish or yellowish-brown colour, and contained greenish-yellow or yellowish-brown flakes, which consisted of intestinal mucus, biliary mucus, with the resins, fatty matter, and colouring matter of the bile. The mucous fluid in the upper third or upper half of the small intestines of the dog and horse, contained

1. Some free acid (lower down in the canal the secretion was for the most part neutral, and in the horse contained bicarbonate of soda).
2. Albumen, in considerable quantity,—probably derived from the pancreatic juice.
3. (In the horse) a matter similar to casein.
4. (In the same animal) a substance precipitated by muriate of tin,—probably salivin and osmazome.
5. (Also in the horse) a matter which was reddened when acted on by chlorine or oxymuriate of mercury.
6. A small quantity of biliary resin.
7. (In the upper part of the small intestine of the horse) a feebly acid substance which contained nitrogen.
8. The usual salts of the animal fluids.

The mucus of the cæcum in dogs was always acid. In the horse, on the contrary, it contained bicarbonate of soda.

Viridet (*De Primâ Coctione*) had previously observed that in the rabbit the cæcum evinced the same acid reaction as the stomach.

Schultz has instituted some further experiments relative to the acid secretion of the cæcum. He found that, when the animals had fasted, the fluid in the cæcum was more frequently alkaline or neutral, although at other times, and during digestion, it was acid; this difference he supposed to arise from the bile reaching the cæcum during fasting and neutralising the acid. It was, however, chiefly in herbivorous animals, which have a long cæcum, that he met with the acid reaction; in the carnivora, in which the cæcum is less developed, there was generally no acidity. Two ounces of chyme taken from the stomach of a rabbit which had been fed with potatoes and grass, and was opened two hours and a half after death, required for saturation three ounces and a half of ox's bile: to neutralise one ounce of the contents of the cæcum of the rabbit five drachms of bile were required. Eighteen ounces of chyme from the stomach of a horse required fifteen grains of carbonate of potash, or two ounces and a half of bile of the ox to one ounce of the chyme; while for one ounce of the contents of the cæcum five ounces of bile were necessary. The chyme from the stomach of a hog required for saturation from 1·04 to 1·11 per cent. of carbonate of potash; the contents of the cæcum, on the other hand, required only 0·78 per cent.

CHAPTER V.

OF THE CHANGES WHICH THE FOOD UNDERGOES IN THE ALIMENTARY CANAL.

Before the solution of the food can take place, it is necessary that the different substances which are used as aliment should lose their organic structure and cohesion; and this is effected principally by mastication. The comminution of the food is performed either in the mouth,—or in the pharynx, where pharyngeal teeth exist, as in fishes,—or in the stomach itself, which then has either cartilaginous parietes, as in the granivorous and insectivorous birds; or teeth, as in some crustacea, insects and mollusca. Mastication, and the subsequent stage of the digestive process, may, in fact, be compared with the usual chemical operations; it is not necessary to ascribe any share in them to organic influence. The chemist reduces to powder the substances which he wishes to dissolve, or from which he desires to extract a particular ingredient, and then digests them in the solvent menstruum; a similar digestion is performed in the crop of birds and in the stomach. After the soluble portion has been dissolved, the chemist separates it by filtration; and in the digestive process, after the trituration and solution, there is likewise a separation of the dissolved from the insoluble parts.

a. Change effected by the saliva.—The saliva prepares the food mechanically for deglutition; whether it contributes in any degree to the solution of the food, and what share its components have in the production of the chemical change in the stomach, are unknown: but, since fishes and Cetacea are not provided with the salivary secretion, it does not appear to play an important part in the process. Spallanzani and Reaumur state, as the result of their experiments, that food inclosed in perforated tubes, and introduced into the stomach of animals, was more quickly digested when it had been previously impregnated with saliva than when it was merely moistened with water.* Tiedemann and Gmelin, too, believe that the carbonates, acetates, and muriates of potash and soda, which enter into the composition of the saliva, give it a solvent property, although a slight one.(?) Berzelius, on the other hand, observes, that saliva alone has no more action on alimentary substances, dissolves no greater part of them, than pure water; and I must confess that I have perceived scarcely any difference between the action of saliva and that of water on meat, in experiments instituted for the purpose of comparison; while those instituted by Dr. Beaumont and Purkinje (*Isis*, 1838. No. 7,) rather tended to show that saliva retards the solvent action of the gastric juice.

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* Spallanzani, Versuche über das Verdauungsgeschaft. Leipz. 1785.—Expériences sur la digestion, par Sennebier. Genève, 1783.

With the so-called dynamic effects of the saliva I am wholly unacquainted. Nor does the saliva appear to act by destroying the peculiar organic properties of the alimentary substances. The action of the poisonous secretion of serpents, and of the saliva of rabid animals, might induce a belief in the saliva having such properties, were it not that the glands which secrete the poison in the poisonous serpents are, as I have already remarked, distinct from the salivary glands, which are present in addition to the poisonous glands,—those latter being special instruments of offence. The infectious principle of rabies, too, is not a property of the saliva alone, but is possessed by all the fluids of the body of the rabid animal.*

The only fact favourable to the opinion that the saliva has a share in the chemical process of digestion in the stomach, is that observed by Leuchs, (*Kastner's Archiv.* 1831,) and confirmed by Schwann and Sebastian (*Van Setten, Diss. de saliva.* Groning. 1837,)—namely, that saliva has the property of changing starch into sugar. And this fact is interesting, inasmuch as starch is in the stomach converted into gum of starch, and gradually into sugar.

b. Change which the food undergoes in the stomach,—action of the gastric juice.—The fluids taken into the stomach are for the most part absorbed from it, and do not even pass the pylorus. The solids are, with the exception of the insoluble parts, reduced to a substance called chyme, which is in part quite fluid, in part consists of globules. The formation of chyme is described by most observers to go on solely at the surface of the food which is in contact with the coats of the stomach; but Dr. Beaumont observed in his numerous experiments, that the gastric juice acts at the same time on each and every particle of food in the stomach, and not merely on the surface of the whole mass.

Observations relative to the changes which the food undergoes in digestion, and to the time occupied by these changes, have been instituted by Gosse, who for that purpose excited artificial vomiting in his own person; (his experiments are detailed by Spallanzani,) by Spallanzani, Stevens, (*De Aliment. Concoct.* Edinb. 1777,) Tiedemann and Gmelin, and Schultz, on animals; and lastly, by Dr. Beaumont in far greater number than by any other physiologist on the human subject.

Spallanzani introduced a tube filled with bread into the stomach of a cat; in five hours the bread was partly dissolved; and for the solution of meat nine hours were required. Even cartilages and bone contained in tubes, and tendons inclosed in linen, were after a longer period softened or dissolved.

Tiedemann and Gmelin having given dogs boiled white of egg to eat, and killed the animals four hours afterwards, found the particles of that substance in part dissolved. Fibrin in the same space of time had become swollen with moisture, and was partly converted into albumen, which was in solution. They found also that animal gelatin loses by digestion in the stomach its property of gelatinising spontaneously, and its peculiarity of being precipitated in shreds by chlorine. Cheese was dissolved without being converted into albumen. Boiled starch was in the course of a few hours converted into gum of starch and sugar. Vegetable gluten, which is insoluble in acetic and muriatic acids, was found unaltered after having been in the stomach five hours. Milk was coagulated; the whey being then removed by absorption, while the curds were redissolved. Raw beef, after having been four hours in the stomach, was found covered with a brown, pulpy, gelatinous mass. Cartilage and bone, after being digested for from two to four hours, appeared somewhat softened at the angles, edges, and surface. Bread was in two and a half hours almost completely dissolved. In the horse the food seemed to leave the stomach in a state less advanced towards solution.

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* Hertwig's Beiträge zur näheren Kentniss der Wuthkrankheit. Berl. 1829, p. 156, 160.

Dr. Beaumont has had the rare opportunity of studying during several years the process of digestion in the person of a man named St. Martin, in whom there existed, as the result of a gunshot wound, an opening leading directly into the stomach, near the upper extremity of the great curvature, and three inches from the cardiac orifice. The external opening was situated two inches below the left mamma, in a line drawn from that part to the left spine of the ilium. The borders of the opening into the stomach, which was of considerable size, had united in healing with the margins of the external wound, but the cavity of the stomach was at last cut off from the exterior by a fold of mucous membrane which projected from the upper and back part of the opening, and closed it like a valve, but could be pushed back by the finger. If, while St. Martin lay on his back, pressure was made with the hand in the situation of the liver, and the body turned at the same time upon the left side, bile flowed through the pylorus, and could be drawn off by means of an elastic gum tube introduced into the stomach. Sometimes, too, though rarely, bile was found mixed with the gastric juice when the above manœuvre had not been practised. Chyme was obtained from the stomach by applying the hand to the lower part of the epigastric region, and directing pressure upwards. When the stomach was full, mere pressure upon the valvular fold which closed the opening was sufficient to cause an escape of the contents. The stomach while empty could be explored to the depth of five or six inches by artificial distention. The food and drink could in this manner be seen to enter it.

Dr. Beaumont has kept a complete journal of the digestive process in this man. The following table shows the time required for the digestion of different kinds of food, which were taken with bread or vegetables, or both.

Articles of diet.	Mode of cooking.	Meal.	Exercise.		Rest.	Remarks.
			Moderate	Increased		
			h. m.	h. m.	h. m.	
Tripe, soused	fried	breakfast	1 0			
Pig's feet, do.	boiled	——	1 0			
Venison steak, fresh	broiled	——	1 35			
Codfish, dry	boiled	dinner	2 0			
Bread and milk	cold	——	2 0			
Turkey	roasted	——	2 30			
Goose, wild	——	——	2 30			
Pig, young	——	——	2 30			
Hashed meat and vegetables	warm	breakfast	2 30			
Oysters	raw	dinner	2 45	. .	. .	oysters suspended in the stomach.
——	stewed	——	3 30	. .	. .	nothing but a little dry bread or cracker taken at these meals.
——	raw	breakfast	3 0	. .	. .	
——	——	dinner	3 0	. .	. .	
——	stewed	——	3 30	. .	. .	
Beef, fresh, fat, and lean	roasted	dinner	3 30			
——	——	——	3 0			
——	——	breakfast	2 45			
——	broiled	——	3 0			
——	——	——	—	. .	3 45	
——	——	——	—	3 30	. .	exercise till fatigued.
——	boiled	——	4 0	. .	. .	morbid appearance of stomach.
——	——	dinner	—	3 30		
——	——	breakfast	3 38	. .	. .	large proportion of fat.
——	——	supper	—	. .	4 0	ditto.
——	——	breakfast	—	. .	4 30	ditto, and in recumbent position.
——	——	dinner	3 30			
——	——	——	—	. .	4 0	
——	——	breakfast	—	. .	4 15	
——	——	——	3 30			
——	——	——	—	. .	4 15	
Beef, salted	——	dinner	5 30			
——	——	——	3 30			
Pork, recently salted	——	breakfast	5 15			
——	——	——	4 30			
——	——	——	5 15	. .	. .	became angry during the experiment.
——	——	——	6 0	. .	. .	unusually full meal.
——	——	——	4 30			
——	——	——	4 30			
——	——	——	4 30			
——	——	dinner	4 30			
——	——	breakfast	—	4 0		
——	——	dinner	—	3 30		
Pork, fresh	roasted	——	6 30	. .	. .	unusually full meal.
——	broiled	——	3 15			
——	——	breakfast	4 30			

Articles of diet.	Mode of cooking.	Meal.	Exercise.		Rest.	Remarks.
			Moderate	Increased		
			h. m.	h. m.	h. m.	
Mutton, fat and lean	roasted	dinner	3 15			
——	broiled	breakfast	. .	3 0		
——	——	——	3 30			
——	——	——	4 30	. .	. .	morbid appearance of stomach.
——	——	dinner	4 0			
——	——	breakfast	4 30	. .	. .	full meal coarsely masticated.
Eggs	hard-boiled	——	3 30	. .	. .	bread, or bread and coffee.
——	soft-boiled	——	3 0			
——	hard-boiled	dinner	5 30	. .	. .	morbid appearance of stomach.
——	——	breakfast	3 30	. .	. .	ditto.
——	soft-boiled	dinner	3 0			
Sausages	broiled	breakfast	3 30	. .	. .	with soft-boiled eggs.
——	——	dinner	3 0			
——	fried	breakfast	4 0	. .	. .	muslin bag, containing the same kind of diet, suspended in the stomach during these experiments; morbid appearance of stomach also.
——	——	——	5 0	. .	. .	
——	broiled	——	3 30	. .	. .	
——	——	——	. .	4 15	. .	full meal, severe exercise.
Fowls (hens)	boiled	——	4 0	. .	. .	with bread and coffee.
——	——	dinner	4 0	. .	. .	with bread and water.
——	——	——	4 0			
Veal, fresh	broiled	breakfast	4 0	. .	. .	muslin bag suspended in stomach.
——	——	dinner	4 0			
——	——	breakfast	4 0			
——	——	dinner	4 45	. .	. .	morbid appearance of stomach.
——	——	breakfast	. .	3 45		
——	——	dinner	4 30			
——	——	breakfast	5 30	. .	. .	ditto.
Soup made of meat and vegetables	. . .	. . .	4 0			
Bread buttered, with coffee	. . .	. . .	4 15	. .	. .	ditto.
Bread dry, with coffee	. . .	. . .	3 45			
Bread dry, with dry mashed potatoes	. . .	dinner	3 45			

We transcribe some of the experiments from Dr. Beaumont's journal as examples. They are not without interest.*

Second series, Exp. 33.—At one o'clock St. Martin dined on roast-beef, bread and potatoes. In half an hour examined contents of stomach, found what he had eaten reduced to a mass resembling thick porridge. At two o'clock nearly all chymified,—a few distinct particles of food still to be seen. At half-past four, chymification complete. At six, nothing in the stomach but a little gastric juice tinged with bile.

Exp. 42.—April 7th, 8 A M. Breakfast of three hard-boiled eggs, pancakes, and coffee. At half-past eight o'clock, examined stomach, found a heterogeneous mixture of the several articles slightly digested. At a quarter past ten, no part of breakfast in the stomach.

Exp. 43.—At eleven o'clock, same day, St. Martin ate two roasted eggs and three ripe apples. In half an hour they were in an incipient state of digestion; and at a quarter past twelve no vestige of them remained.

Exp. 44.—At two o'clock P. M. same day, dined on roasted pig and vegetables. At three o'clock they were half chymified, and at half-past four nothing remained but a very little gastric juice.

Third series, Exp. 18.—On December 17, half-past eight A. M. two drachms of fresh-fried sausage in a fine muslin bag suspended in the stomach of St. Martin, who immediately afterwards breakfasted on the same kind of sausage, and a small piece of broiled mutton, wheaten bread, and a pint of coffee. At half-past eleven, stomach half empty; contents of bag about half diminished. At two o'clock P. M. stomach empty and clean; contents of bag all gone except fifteen grains, consisting of small pieces of cartilaginous and membranous fibres, and the spices of the sausage, which last weighed six grains.

Exp. 26, second series,—in which Dr. Beaumont examined the state of the food at intervals during the process of digestion,—showed very clearly that animal substances are dissolved much more rapidly than vegetables.

Dr. Beaumont has observed that *the temperature of the stomach* does not become elevated during digestion; it is constantly 100° Fahr., and it is only during muscular exertion that it rises some degrees, like the temperature of other parts of the body.

The gas contained in the stomach is during digestion generally very small in quantity. Magendie and Chevreul obtained some from the stomach of an executed criminal, and found it to consist of

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* The translator has omitted the first experiment, since Dr. Beaumont himself points out that the apparent results of it cannot be depended on. It is worth while to note, however, that, during the experiment, St. Martin complained of distress and uneasiness at the stomach, and that on the following day the same symptoms continuing, with pain of head, costiveness, a depressed pulse, dry skin, and coated tongue, numerous white spots or pustules resembling coagulated lymph were seen spread over the inner surface of the stomach, and that Dr. Beaumont has observed a similar appearance of the stomach on other occasions attending symptoms of indigestion.

Oxygen,	11·03
Carbonic acid,	14·00
Hydrogen,	3·55
Nitrogen,	71·45

The components of the chyme, according to the analysis of Tiedemann and Gmelin, are:—

1. Albumen,—in the chyme of dogs which had been fed with boiled eggs, fibrin, meat, bread, and vegetable gluten; it was less in quantity when the dogs had eaten liquid white of egg, cheese, glue, and bones.

2. A substance resembling casein,—in the chyme of dogs fed with liquid white of egg and fibrin.

3. A substance precipitated by muriate of tin (probably osmazome and salivary matter),—in chyme resulting from the digestion of vegetable gluten, cheese, and milk, in dogs, and of starch and oats, in horses.

Dr. Marcet pointed out,—and his observation has been confirmed by Dr. Prout,—that the chyme in dogs contains much more albumen when the animal has been fed on animal substances than when it has been fed with bread. (*Thomson's Annals of Philos.* 1819.)

Digestion in ruminants.—The fluid expressed from the mass of food in the first and second stomachs of ruminating animals, is stated, as well by Tiedemann and Gmelin, as by Prevost and Le Royer, (*Biblioth. Universelle de Genève,* t. xxvii. p. 229,) to contain albumen held in solution by an alkali, which in the state of carbonate is an ingredient of the secretion of these cavities. The proportion of albumen in the fluid varies; when the food consisted of oats, it was in such abundance that it coagulated at the temperature of 158° Fahr. A development of gas, consisting of sulphuretted hydrogen, carbonic acid, and carburetted hydrogen, of which the two former are dissolved in the fluid, while the last retains its gaseous form, takes place during digestion in the first and second stomachs. (*Berzelius, Chemie Animale.*)

The contents of the fourth stomach, which is even more acid than the third, were found by Tiedemann and Gmelin to be in the calf coagulated milk, in the ox a soft yellowish brown pulp.

The components of the chyme in the fourth stomach were:—

1. Albumen,—in the ox and calf.

2. A substance reddened by the action of muriatic acid,—in the ox and sheep.

3. A substance precipitated by muriate of tin,—in the sheep.

Digestion in birds.—The fluid resulting from the digestion of the food in the crop of birds, was found by Tiedemann and Gmelin to contain albumen in a state of solution, and in such large proportion that the fluid was sometimes coagulable by heat; the coagulating substance being animal albumen when the food of the bird had been meat, vegetable albumen when the food had consisted of corn and peas. The albuminous matters were still more abundant in the muscular gizzard.

Theory of digestion.

Many of the older theories of the digestive process,—for example, that which supposed it to consist in attrition by the stomach,—are now evidently of mere historical interest. In by far the greater number of animals, the stomach is unprovided with mechanical instruments for the aid of digestion; (see page 338, *et sequent,*) and the experiments of Reaumur and Spallanzani have demonstrated that substances enclosed in perforated tubes, and consequently protected from mechanical influence, are not the less easily digested. It is, in like manner, scarcely necessary to remark that the theory of digestion by putrefaction is equally groundless; no signs of putrefaction being presented by the digested food, although, if the same substances were left to spontaneous decomposition at the temperature of 99½° Fahr., they would very quickly evidence marks of the putrefactive process. Moreover, when substances in which putrefaction has already commenced, are subjected to digestion in the stomach, the putrefactive change is, as Spallanzani has shown, immediately checked in them.

In the present state of our knowledge of the subject, we have in the first place to decide,—

1. Whether digestion consists essentially in the articles of food undergoing in the stomach some chemical change, such as fermentation or oxidation, by which they are deprived of their cohesion and reduced to a pulp, there being no gastric solvent fluid; but, according to this view, the so-named gastric juice being the product, not the cause, of digestion.

2. Or whether digestion is really a solution of the food by a solvent menstruum,—the gastric juice.

We recognise the first of these views in the fermentative theory of Boerhaave, and it has been recently brought forward anew by C. H. Schultz in his hypothesis of the reduction of the food by oxidation.

The theory of digestion by fermentation does not, however, preclude the existence of an active gastric fluid. The theory of fermentation supposes that the food is reduced by a chemical action of its components on each other, this action being excited either by a portion remaining from the last digested food, or by a ferment secreted by the stomach itself, the acids of the stomach being the product of the fermentation. This theory has never been confirmed by proofs, and can now, indeed, be refuted.

The fermentation, if it exists, must be different from all other known kinds of fermentation; for, as we shall presently show, none of the usual phenomena of that process are present when digestion is performed artificially.

Schultz does not, it is true, set out on the supposition of the existence of a fermentative process in digestion; but still his theory is in principle similar, inasmuch as he supposes that the food is not dissolved by a peculiar fluid, but undergoes decomposition, and loses its cohesion, in consequence of being oxidised,—that the acid of the chyme is not the cause of this change, but the product of it.

The existence of a special digestive fluid had been already denied by Montègre. Having found that, after vomiting, and then neutralising any fluid that remained in his stomach by means of magnesia, food was still digested, and an acid chyme produced, he concluded that the fluid called gastric juice is nothing more than saliva and gastric mucus changed by the process of chymification. But it is evident that here the chymification might with equal probability have been ascribed to the secretion of fresh gastric juice.

The arguments adduced by Schultz in support of his theory are, first,—that no special solvent gastric secretion exists; that the matter regarded by Tiedemann and Gmelin as such, was merely a remaining portion of chyme: that no acids are formed in the stomach except during digestion, and that their production cannot be excited by mechanical irritation of the coats of the stomach. This statement is, however, opposed to the concordant results of direct observations, not only to those of Spallanzani, and Tiedemann and Gmelin, but also to the much more conclusive experiments of Dr. Beaumont. Secondly,—Schultz adduces the analogy of vegetables, in which the nutritive matters undergo a change of this sort, and in which the nutritive material of the germinating seeds is converted by a kind of oxidation into acids and sugar, and rendered soluble. These arguments are very ingenious; but the question is, whether in *animals* there is not really a peculiar fluid secreted by the stomach which will dissolve the articles of food even out of the body? and, even if we disregard the imperfect experiments of earlier physiologists, we shall find in the numerous observations of Beaumont, Eberle, and others, satisfactory proofs that there is such a fluid. Lastly,—Schultz adduces the fact of the coagulation of the milk in the stomach as an example of the conversion of a substance which is not acid into an acid chyme. Milk is coagulated, he says, by an infusion of the stomach of a calf which has been dried and deprived of its acidity by neutralisation with carbonate of potash, and even by an infusion of the fresh stomach of a dog which has been made to fast forty hours, so that the stomach was distinctly alkaline; and milk will coagulate, he remarks, in the stomach of sucking whelps after the stomach has been free from food during twelve or sixteen hours, and is neutral or alkaline; the only difference being that the coagulation takes place more slowly than when the stomach contains acids. It is quite true, as Berzelius had already pointed out, that the acid of the stomach is not the only cause of the coagulation of the milk; for there is now known to be a peculiar organic principle of the gastric secretion which has the same property.

In the state of the inquiry, nearly up to the present time, the questions to be decided were:—1. Whether a gastric juice exists. 2. Whether this gastric juice, whatever is its nature, has the property of dissolving the substances used as food, not only in the stomach, but also out of the body. 3. Supposing the last question were answered in the affirmative, whether the solution be effected by the agency of the acid ingredients of the gastric juice, or by some other principles which it can be demonstrated to contain. 4. Whether the solution is attended likewise with a change in the chemical composition of the alimentary substances.

1. *Is there a special gastric juice?*—This question has been already decided in the affirmative in the preceding Chapter, in which were related the numerous experiments of Tiedemann and Gmelin, and the still more conclusive observations of Dr. Beaumont, who excited in St. Martin by mechanical irritation the secretion of gastric juice when the stomach contained no food, and collected it in considerable quantity by means of a tube introduced through the accidental opening into his stomach.

2. *Has the gastric juice the property of dissolving food submitted to its action, whether in the stomach or out of the body?*—The answer to this question depends wholly on our being able to dissolve food artificially by means of gastric juice mixed with it out of the body. Attention was first directed to artificial digestion by the experiments of Spallanzani. That physiologist obtained some of the secretion of the stomach of birds, by causing them to swallow small pieces of sponge, which he withdrew after some little time by means of threads attached to them; the fluid thus obtained he mixed with food previously masticated, and put the mixture into small glass vessels in which he kept up the proper warmth by placing them in his axillæ. The contents, after the lapse of fifteen hours or two days, appeared to be converted into chyme. The statements of Spallanzani seemed, however, to be refuted by the observations of Montègre, which were submitted to the French Academy in 1812. The gastric fluid which Montègre employed in his experiments, was the secretion of his stomach during fasting, which he had the power of vomiting at will; it was in most cases distinctly acid. Dr. Stevens obtained from artificial digestion a result similar to that announced by Spallanzani.

More recently, Tiedemann' and Gmelin have instituted similar experiments with gastric fluid obtained from two dogs.

In their first experiment, three grammes (about forty-six grains) of boiled beef were submitted to the action of ten grammes (about two and a half drachms) of the gastric fluid; in a second vessel, a cubic mass of bread freed from crust with the same quantity of the fluid, and in a third and fourth, similar portions of meat and bread were placed, each closely enveloped in a piece of the mucous coat of the stomach; lastly, similar portions of meat and bread were placed in a fifth and a sixth vessel with water. All the vessels were exposed, during a period of eight hours, to a temperature of from 86° to 104° Fahr. At the end of that time, the meat in the gastric juice was reduced at its surface to a reddish-white very soft pulp, which could be easily scraped off; the meat enveloped in the mucous membrane had no such pulpy layer covering it, and was but little softer than that which had been macerated in pure water; the latter was quite hard, and nothing perceptible could be scraped from its surface.

The bread in the gastric juice was converted into a soft whitish mass; that in the mucous membrane was nearly as soft; the bread in the water less so.

In the second experiment, they had sixty-two grammes (about sixteen drachms) of gastric juice. They disposed in separate vessels, 1. gastric juice with raw beef; 2. gastric juice with boiled white of egg; 3. water and beef; 4. water and white of egg; 5. water with ten drops of distilled vinegar and beef; 6. water with the same quantity of vinegar and white of egg. The vessels were kept, during the period of ten hours, at the same temperature as in the former experiment. The meat macerated in the gastric juice was then found of a pale red, and very much softened on its surface,—a pulpy matter could be scraped from it; the white of egg in the gastric juice was likewise very much softened, and had much the appearance of white of egg from the stomach of a dog which had been fed with it. The meat in the water was whitish and firm; the white of egg also, which had been macerated in water only, was quite solid. The substances in the dilute vinegar presented no trace of softening. (*Tiedemann and Gmelin, loc. cit.*)

Dr. Beaumont's experiments on artificial digestion are of extraordinary interest. They demonstrate most satisfactorily that the stomach secretes a fluid which has the power of dissolving articles of food even out of the body.* As an example, we may instance the 2nd experiment in the 1st series. Dr. Beaumont having, after St. Martin had fasted seventeen hours, obtained from his stomach, by the method which we have already mentioned, one ounce of gastric juice, put into it a solid piece of recently boiled beef weighing three drachms, and placed the vessel which contained them in a water-bath heated to 100.° In forty minutes digestion had commenced on the surface of the meat; in fifty minutes, the fluid was quite opaque and cloudy, the external texture began to separate and become loose; and in sixty minutes, chyme began to form. At 1 p. m. (two hours after the commencement of the experiment) the cellular texture was destroyed, the muscular fibres loose and floating about in fine small threads very tender and soft. In six hours, they were nearly all digested,—a few fibres only remaining. After the lapse of ten hours, every part of the meat was completely digested. The gastric juice, which was at first transparent, was now about the colour of whey, and deposited a fine sediment. A similar piece of beef was, at the time of the commencement of this experiment, suspended in the stomach by means of a thread; at the expiration of the first hour, it was changed in about the same degree as the meat digested artificially; but at the end of the second hour, it was completely digested and gone.

In other experiments Dr. Beaumont withdrew, through the opening into the stomach, some of the food which had been taken twenty minutes previously, and which was completely mixed with the gastric juice. He continued the digestion, which had already commenced, by means of artificial heat in a water-bath. In a few hours, the food thus treated was completely chymified; and the artificial seemed to be but little slower than the natural digestion. (See expts. 25, 26, and 27, second series.)

Several of Dr. Beaumont's experiments,—we may mention, expt. 31, second series, and expts. 28, 33, and 48, third series,—demonstrate the influence of temperature, and of the quantity of the gastric juice, on digestion. Experiment 31 of the second series, which, with many others, also, contrasts the action of water with that of the gastric juice on organic substances, may serve as an example. Having obtained from the stomach of St. Martin two ounces of gastric juice, he divided this quantity into two equal portions, and laid in each an equal quantity of masticated roast-beef. One he placed in a water-bath at the temperature of 99° Fahr. and left the other exposed to the open air at a temperature of 34° Fahr. A third similar portion of meat he kept in a phial with an ounce of cold water. An hour after the commencement of the experiment, St. Martin had finished his breakfast, which consisted of the same meat, with biscuit, butter, and coffee. Two hours after the meat had been put into the phials, the portion in the warm gastric juice was as far advanced towards chymification as the food in the stomach; the meat in the cold gastric juice was less acted on, and that in the cold water was merely a little macerated.

In two hours and forty-five minutes from the time that the experiment was begun, the food in the stomach was completely digested, and the stomach empty, while even at the end of six hours the meat in the gastric juice was only half digested. Dr. Beaumont, therefore, having procured twelve drachms of fresh gastric juice, added now a portion to each of the phials containing meat and gastric juice, and to a portion of the half-digested food which he had withdrawn from the stomach two hours after the commencement of the experiment, and which had not advanced towards solution. After eight hours' maceration, the portions of meat in the cold gastric juice and in the cold water were little changed; but, from the time of the addition of the fresh gastric juice, digestion went on rapidly in the other phials which were kept at the proper heat; and at the end of twenty-four hours the meat which had been withdrawn from the stomach after digestion had commenced, was, with the exception of a piece which had not been masticated, converted into a thickish pulpy mass of a reddish brown colour: the other portion of meat in the warm gastric juice was also digested, though less perfectly; while that in the cold gastric juice was scarcely more acted on than the meat in the water, which was merely macerated. Dr. Beaumont now exposed these two phials containing the meat in cold gastric juice and meat in water to the heat of the water-bath for twenty-four hours, and the gastric juice which, when cold, had no action on the meat, now dissolved it; while the meat in the water underwent no change, except that, towards the end of the experiment, putrefaction commenced.

The 48th expt., third series, illustrates the antiseptic power of the gastric juice. A piece of meat which had been macerated at the temperature of digestion in water for several days till it acquired a strong putrid odour, on the addition of some fresh gastric juice, lost all signs of putrefaction, and soon began to be digested and chymified.

To justify our confidence in Dr. Beaumont's statements, we may mention that he always relates the accidental circumstances which occurred in the experiments, and refers to several other physicians, Drs. Silliman, Knight, Yves, Hubbard, Dunglison, Sewall, Jones, and Henderson, as having interested themselves in them. It must therefore be regarded an indubitable fact, that the gastric juice is really a solvent for organic substances, both in the stomach and out of the body.*

3. *Are the solvent principles in the gastric juice acids, or other unknown substances?*—Tiedemann and Gmelin were inclined to favour the theory which attributes the solution of the food in the stomach, to the action of the acids contained in the gastric juice,—namely, of the acetic and muriatic acids.

For the purpose of ascertaining the degree of solvent action exerted by the acids of the stomach, on some organic matters which are not soluble in water, they submitted to the action of these acids at a temperature of about 50° Fahr. during some weeks the following substances:—1. fibrin from the blood of calves; 2. fibrin from the blood of the ox; 3. fibrin from the blood of the horse; 4. the coats of the large venous trunks of the horse; 5. the coats of the larger arterial trunks of the same animal; 6. the white of a hen's egg boiled hard; 7. mucus from the small intestine of a dog; 8. mucus from the small intestine of a horse. The proportions of the fluid and the solid substance (which was weighed in the moist state), the temperature, and the duration of the experiment, were in each case the same.

Acetic acid was completely absorbed by the substances 1, 2, and 4; these swelled up, and became each a transparent mass which, when heated with a fresh portion of acid, was completely dissolved. A small quantity of the acid digested with each of the substances 3, 5, and 6, remained unabsorbed, and afforded a copious precipitate with tincture of galls and ferro-prussiate of potash. The remaining masses of 3 and 5 were swollen; and, on being heated with a fresh portion of acid, became more gelatinous, and were for the most part dissolved. The substance 6 was less swollen, and underwent less change when heated. The mucus, 7 and 8, at first remained nearly unchanged, and the acetic acid in which it had been macerated did not become turbid on the addition of tincture of galls; but, on being heated with fresh acetic acid, it was nearly wholly dissolved.

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* We can therefore be no longer surprised that the stomach is sometimes found to undergo softening sooner than other parts of the body after death; it being acted on by the solvent gastric juice. The phenomenon has been observed more particularly in rabbits and in children, and has by many been attributed to putrefaction. (See Rudolphi's Physiol. ii. 2. 119.) I have observed it in rabbits, and know that in them it did not depend on the mode of death. It is certainly owing to a decomposition, of which, however, the cause must be local and "material," and probably is no other than the chemical action of the gastric juice.

The *muriatic acid* had, without the application of heat, dissolved a great part of the substances 1—6, judging by the abundance of the precipitate produced by the addition of tincture of galls; of the mucus, on the contrary, it had dissolved very little.

Dr. Beaumont, likewise, has instituted several experiments with a view to determine the power of acids in dissolving articles of food; and the results which he obtained, although they varied somewhat according to the substances employed in the experiments, have nevertheless led him to the conclusion that no other fluid produces the same effect on food which the gastric juice does, and that *it* is the only solvent of aliment.

He found that common vinegar exerts no more action than water on white of egg digested in it and kept warm in the axilla; even after five hours' maceration, scarcely any diminution of weight had taken place; while a similar portion of the same substance submitted during the same period of time to the action of an equal quantity of gastric juice, under exactly the same circumstances, was completely dissolved. (Expt. 46, fourth series.)

Dr. Beaumont made a mixture of muriatic and acetic acids, each diluted to the same degree of acidity as the gastric juice, (judging of this by the taste,) in the proportion of three parts of the dilute muriatic acid, and one part of dilute acetic acid, and compared the action of this fluid with that of an equal quantity of gastric juice from the stomach of St. Martin, on different substances, both menstrua being kept at the proper temperature for digestion.

Roast beef, cut small, was in 6¾ hours nearly entirely dissolved by the gastric juice; while in the mixed acid it merely lost its fibrous appearance, and became a gelatinous mass. After the digestion had been continued eight hours longer, the acids had dissolved all the meat, with the exception of a small portion of gelatinous substance which remained on the filter; but the solution, instead of being a turbid whitish grey fluid depositing a brown sediment on standing like the product of digestion in the gastric juice, was of a reddish brown colour and yielded no sediment. The action of infusion of galls on the two fluids was very different. (Expt. 115, third series.)

There was the same difference in the time required for the solution, and in the products of the digestion, of boiled beef coarsely masticated, in the acids, and in gastric juice. (Expt. 104, third series.)

Isinglass appeared to be more soluble than meat in the mixed acids, but it was nevertheless not so soluble in them as in gastric juice; and the resulting fluid differed from the solution of the same substance in gastric juice, although the differences were less marked in some experiments than in others. (Expts. 105 and 106.)

Saliva acidulated with acetic, or with muriatic acid, so as to resemble in taste the gastric juice, did not possess the solvent properties of the latter fluid. (Expt. 96.)

I had myself long since instituted some experiments, with the view to determine whether the theory that the acids are the solvent principles of the gastric juice was correct. I placed small pieces of meat of some grains in weight, and small cubes of coagulated white of egg, in equal quantities of very much diluted muriatic, acetic, tartaric, and oxalic acids; and although after maceration for a short time, a precipitate or turbidity could be produced in the liquid by ordinary re-agents, showing that a part of the substances had been dissolved, yet I found the masses of meat and albumen by no means perceptibly changed, even after the lapse of several days;—indeed, the small cubes of coagulated white of egg preserved their angles and edges for weeks. The action was not much greater when the maceration was performed at the heat of natural digestion. Of all the acids of which I tried the solvent power, and which I have named above, the oxalic, known to be poisonous to the human body even in small doses, appeared to have the most powerful action on the substances submitted to it; the fluid became turbid in a short time, and deposited a scanty whitish sediment, but the portions of meat and albumen gave evidence nevertheless of no particular change. At the same time that I was making these experiments, I exposed a glass containing dilute acetic acid and small pieces of meat, during the space of twenty-four hours, to the current of a powerful galvanic battery; I made a similar experiment with solution of common salt; but in neither case was the solution of the organic substance in any perceptible degree accelerated.

The acids which are such powerful solvents for mineral substances, are extremely feeble in their action on organic matters; and if we only remember that dilute or even concentrated acids are inadequate to dissolve completely a small piece of meat or white of egg of the weight of a few grains, though their action is continued for several days, the theory apparently so simple which ascribes the solution of the food to the agency of the acids of the stomach, will cease to appear probable. Its insufficiency must, indeed, have been always evident to those who reflected how frequently indigestion is attended with increased secretion of acid. It must, therefore, be allowed that no investigations, thus far, have informed us of the nature of the active solvent principle of the gastric juice. Berzelius long since made this confession. Everything tended to convince us that the active principle of the gastric juice is an organic substance, of which the action is similar to that of "Diastase" on starch. Such was the state of our knowledge on the subject of digestion before the recent important discoveries of Eberle and Schwann.

Nature of the digestive principle.—Eberle (*Physiologie der Verdauung.* Würzburg, 1834,) discovered that, although neither dilute acids nor mucus alone possess the property of dissolving rapidly organic substances submitted to their action, yet mucus mixed with acids has this solvent power; and that albumen or meat digested with acidulated mucus, or with an infusion of mucous membrane in dilute acid, is not merely quickly dissolved, but also undergoes a chemical change, the albumen losing its property of coagulability and being converted into osmazome and salivary matter.

The experiments of Eberle have been repeated by Schwann and myself, (*Müller's Archiv.* 1836, p. 68,) and by many others, and have been found in the main quite correct. But Eberle was in error in his statement that all mucus, in an acid state, has the property which is possessed by an organic principle secreted with the gastric mucus only;* the mucus of other organs exerts no solvent power: thus, the mucous membrane of the bladder, treated with muriatic acid, was found by Schwann not to have this property. The infusion of the mucous membrane of the fourth stomach of the calf in dilute acid affords digestive fluid. The mucous membrane being dissected from the other coats, washed with cold water until it no longer gives evidence of containing a free acid, and then dried, can in that state be preserved, and is at all times ready for use.

The principal phenomena of artificial digestion may be demonstrated in a simple manner by the following experiment:—The dried mucous membrane is cut into pieces; some of these are placed in each of five test tubes, and distilled water poured over them. To the contents of two of the tubes, six or eight drops of muriatic acid are added: to two others, twelve or fourteen drops of acetic acid. The mucous membrane and water in the fifth glass are left without any addition of acid; and in a sixth is placed the same quantity of water, with eight drops of muriatic acid, but no mucous membrane. Small cubes of coagulated white of egg and boiled meat of several grains' weight are then placed in each of the tubes. After digestion for twelve hours at a temperature of about 99½° Fahr., the pieces of meat and white of egg present the following appearances:—Those macerated in the dilute acid without mucous membrane, or in the water with mucous membrane, but without acid, are unchanged; and the substances in the water alone give out after a time a putrid odour. The pieces of meat and albumen in the acid infusion of mucous membrane are, on the contrary, softened. The coagulated albumen is become transparent, cheesy in the centre, and breaks down easily under pressure. If the digestion is continued for twenty-four hours, the substances in the acid infusion of mucous membrane are dissolved either entirely, or in greater part; and the fluid acquires a peculiar odour, not of a putrescent character, but similar to that of soldier's bread; its taste is acid, and not agreeable. (The fibrin of the blood likewise is dissolved very quickly.) The ordinary temperature of the atmosphere in summer is sufficiently high for the success of the experiment; the surface of the masses of coagulated albumen becomes transparent even in a few hours, and is surrounded by a cloud of particles of albumen, which are for the most part in solution. The albumen which has been dissolved by the digestive fluid, has lost all its former characters, it is no longer coagulable; and the solution contains osmazome and salivary matter, and, according to Schwann, a third substance similar to albumen, which is precipitated by carbonate of soda, is insoluble in water and alcohol, and is soluble in dilute muriatic and acetic acids. This third substance is precipitated neither by the boiling temperature, by acetate of lead, nor by alcohol; but is thrown down in large quantity by nitric acid, and oxymuriate of mercury, and less copiously by cyanuret of iron and potassium, and by tincture of galls.

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* Wasmann has observed that, in the pig, that part of the mucous membrane of the stomach which he has discovered to be composed of columns of cells possesses the solvent power in a much greater degree than other parts,—an observation which the translator has verified.

We found that neither carbonic acid is evolved nor oxygen gas absorbed during artificial digestion, in both which circumstances it differs from the fermentative process. (*Müller and Schwann, loc. cit.*)

The experiments of Eberle, and those instituted by Schwann in conjunction with myself, still left it uncertain whether the digestive principle in an undissolved state acts by the influence of contact, or whether it is itself in solution and acts by dissolving the organic substances. Schwann,* however, has discovered that the infusion of mucous membrane with dilute acid, even after it is filtered, still retains its digestive power. The digestive principle, therefore, is clearly in solution, and the theory of digestion by contact falls to the ground. The clear filtered fluid has the colour of saturated urine; it retains its solvent property for mouths. The proportion of acid recommended by Schwann for the preparation of the digestive fluid, is 3.3 grains to half a loth (about a quarter of an ounce) of the mixture of mucous membrane and water. If the proportion of the acid remains the same, the quantity of the fluid, as compared with that of the membrane, is not of much importance; the weight of the water may be twice or five times that of the mucous membrane in its moist state.

Schwann has performed several experiments to determine the part which the acid plays in the digestive fluid. The experiments already detailed prove that the acids are necessary; but it was possible that they might serve merely for the production of the digestive principle, and might, after this was formed, be no longer essential. This, however, is not the case; the digestive fluid, when neutralised with carbonate of potash was inert, but recovered its power on the addition of the proper quantity of muriatic acid. To ascertain whether the acid acts the part of a mere solvent of the digestive principle, Schwann added to some of the fluid as much carbonate of potash as neutralised more than half the acid of the fluid, which was still acid, and remained clear and without sediment; so that the digestive principle could not have been precipitated, and yet the solvent power of the fluid was lost. The acid therefore is more than a mere solvent of the active principle. It still appeared possible that the acid might enter into a chemical combination with the digestive principle, forming a compound similar to the acid salts. But if such were the case, the quantity of acid necessary ought to be regulated by the quantity of the organic digestive principle; and Schwann found that it was not so: on the contrary, the necessary quantity of the acid bore no relation to the quantity of the organic digestive principle, but was regulated by the quantity of the fluid. Again, the acids do not serve simply to dissolve the products of digestion; for although these are soluble in acids, and even in very dilute acids, yet a quantity of the digestive fluid which is adequate to the solution of a certain quantity of albumen, loses its solvent power when diluted. Lastly, if it were the part of the acids to enter into combination with the products of digestion during their formation, the proportion of the acids in the fluid ought to become less as the digestion advances; but their proportion undergoes no change. Dr. Schwann infers, therefore, that the dilute acids, without themselves undergoing any change, aid by their presence in effecting the decomposition of the organic substances, just as they aid in the conversion of starch into sugar when boiled with it.*

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* Müller's Archiv. 1836, p. 90. Schwann, über das Wesen des Verdauungs processes.

The artificial digestion by means of the acid infusion of gastric mucous membrane may be compared with fermentation, and with the cases of decomposition by contact; inasmuch as both in it, and in these processes, a very small quantity of the decomposing agent is sufficient to produce the effect.† But it results also, from Schwann's observations, that the action of the digestive fluid induces the loss of a part of its power, and not the production of a new active principle, as in the process of fermentation. Moreover, no carbonic acid is developed during artificial digestion, and not the smallest quantity of oxygen is necessary to the process, as has been demonstrated anew by Schwann in still more accurate experiments. Many substances which disturb the progress of the vinous fermentation, likewise interfere with digestion; thus, as Schwann shows, alcohol‡ and the boiling temperature render the digestive principle inert; the same is the action, in a less degree, of the neutral salts, and particularly of the sulphites. But arseniate of potash, which puts a stop to the vinous fermentation, was found by Schwann not to disturb the artificial digestive process.

Chemical properties of the digestive principle.—It must be almost impossible to obtain the solvent principle of the digestive fluid in a separate state, on account of its active property being so easily destroyed by re-agents. Several of Schwann's experiments show the action of different substances upon it. It is not precipitated when the acid of the mixture is neutralised; on the contrary, it is soluble in water alone; it is precipitated from the neutral solution by acetate of lead, and can be obtained again in an active state from the precipitate by means of hydro-sulphuric acid. Ferro-cyanuret of potassium, as well as ferro-cyanide of potassium, produce a precipitate in the acid solution of the digestive principle, but none in the neutral solution; but the precipitates which they throw down, do not contain the digestive principle; the fluid retains its solvent property. Corrosive sublimate produces a precipitate both in the acid and in the neutral fluid. Tannin throws down a precipitate, alcohol and the boiling heat cause turbidity, and all these agents render the fluid inert. Acetic, muriatic, nitric, and sulphuric acids, added in small quantities to the watery extract of the digestive mucous membrane, produce a precipitate, according to Wasmann, which is re-dissolved on the addition of more acid. But if any of the three mineral acids is added in much larger quantity, a second precipitate is thrown down, and the solvent power of the pepsin is destroyed. The solvents of the digestive principle are water, and dilute muriatic and acetic acids. These characters, as well as its peculiar action on casein, justify us in regarding the digestive principle as a peculiar substance, to which, although we cannot procure it in a separate state, we may, on account of its properties, give the name of "pepsin."

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* Although acids are such feeble solvents of organic substances, and particularly of albumen at ordinary temperatures, and even at that of natural digestion; yet white of egg when boiled in dilute acids, is, according to Wasmann, (De digestione nonnulla. Berol. 1839, and Froriep's Notizen. April, 1839,) very rapidly dissolved. He supposes, therefore, that the acids are the essential solvent agents in digestion, and that the pepsin has merely the office of rendering their action rapid at a temperature at which it would otherwise be slow.

† 4·8 grains of digestive fluid, or 0·11 grains of dry residue of the fluid, were sufficient when diluted for the solution of 60 grains of moist albumen, or about 10 grains of solid matter.

‡ The precipitate thrown down by alcohol in the watery solution of pepsin, when re-dissolved in dilute acid, has, however, according to Wasmann, still the power of dissolving white of egg, and the other properties of pepsin; and Purkinje states that alcohol does not destroy the digestive principle.

The action of the digestive principle on casein deserves a more particular consideration. Berzelius had already pointed out that the rennet of the calf has the property of coagulating milk, even after all traces of acidity have been removed by washing. It is known, too, that the coagulation of the casein produced by rennet is peculiar, inasmuch as the curds are insoluble in water, while the coagula of casein produced by alcohol or acids are again soluble in water, and in an additional quantity of acid. Now Schwann has shown that this property of coagulating the casein is possessed by the artificial digestive fluid even when neutralised. On the addition of a very small quantity of the acid fluid to milk, and the application of heat, the coagulated casein soon separates: of the neutral fluid, more than 0.42 per cent. are necessary: but 0.83 are sufficient. The power of the artificial digestive fluid to coagulate milk is destroyed by the boiling temperature; it cannot, therefore, be the saline ingredients which produce the coagulation. This peculiar action of the digestive principle on milk, renders the latter fluid a test for its presence; if a neutral fluid coagulates milk, but loses this property immediately on being boiled, we may infer that it contains the digestive principle. Schwann has in this way proved that the digestive principle which we are here considering, really exists in the stomach. He divided the stomach of a rabbit, which had died immediately after birth, into two portions; boiled one, and then added to each some milk. On the application of a gentle heat, the milk coagulated in the portion which had not been boiled, while in the other it remained unchanged. Wasmann, however, found that the watery extract of the mucous membrane of the stomach of the adult pig or rabbit, of the fourth stomach of the ox, or of the human stomach, had not the property of coagulating milk; and that when acidulated, it had not this power in a greater degree than dilute acid of the same strength. He, therefore, imagines that the property in question must be possessed by the stomach only so long as the animal sucks,—an opinion, opposed, however, to the observation of Schultz, (page 384.)

The solution of some of the alimentary substances is effected not by the digestive principle, which we have named pepsin; but by the acids, either principally, or with the aid of another organic matter.—The substances easily soluble in the digestive principle are fibrin, muscular substance, and coagulated albumen; while casein, gelatin, and vegetable gluten appear, from Schwann's experiments, not to be dissolved by it: for when they were digested separately with diluted acids and dilute digestive fluid, no difference could be perceived in the change which they underwent in the two fluids; while the solutions resulting from the digestion of these substances in the mere dilute acids, displayed the same characters with re-agents as were observed by Tiedemann and Gmelin in the products of the solution of the same substances in natural digestion, with the exception of those due to the starch, which were absent here. The gelatin lost its property of coagulating; and tincture of iodine threw down a precipitate in the solution of gluten in the dilute acid, but produced no change of colour.

The action of an acid is not adequate to explain the changes which starch undergoes in natural digestion; namely, its conversion into gum of starch and sugar. The digestion of starch in dilute acid, even with the addition of some of the artificial digestive fluid, does not give rise to the formation of any sugar. But Schwann has verified the statement of Leuchs, that starch is converted into sugar by the action of saliva. He digested in some acidulated saliva, for twenty-four hours, a certain quantity of boiled starch, then filtered the fluid, and found that iodine produced in it no change of colour. Having neutralised it, and evaporated it to dryness, he obtained from the residue by means of alcohol a considerable quantity of sugar, which he recognised by its taste as well as by its property of fermenting with yeast. The part of the residue which the alcohol did not take up, consisted of the salivary matter of the saliva, in part altered in its properties, and of starch changed to a substance resembling gum, which did not with iodine strike the colour which characterises starch. (*Schwann, loc. cit.*)

Since the activity of the digestive principle depends on the presence of a free acid, it is easy to understand how a neutral gastric fluid holding saline matters in solution can, as Purkinje has observed, (*Müller's Archiv.* 1838, p. 1,) be rendered active by the agency of galvanism, which will decompose the salts and set free the acid at the positive pole.

Influence of the nerves and electricity on digestion.—It has indeed been supposed that electricity is capable of replacing the influence of the nervus vagus in digestion when this influence has been lost. The digestive process is nearly entirely arrested by the division of the vagus nerves on both sides. Blainville, having performed the experiment on pigeons, observed that the vetches which they swallowed afterwards remained unaltered in their crop, and that the process of chymification was wholly arrested. The same result attended similar experiments by Legallois, Dupuy, Dr. Wilson Philip, Clarke, Abel, and Hastings. While, on the other hand, Broughton, Magendie and Leuret, and Lassaigne state that digestion appeared to them to be uninfluenced by the division of the nerve in question. Mayer (*Tiedemann's Zeitschrift*, ii. 1,) also found that the digestive process continued for a certain time, and that acid chyme was formed—at all events in rabbits. Brachet, (*Recherches sur les fonct. du Syst. Gangl. Paris*, 1830,) too, states, that in all his experiments the food underwent chymification at the parts where it was in contact with the coats of the stomach.

The question cannot, however, be determined with complete certainty in quadrupeds, on account of death taking place in them so soon after the operation; I have therefore, in conjunction with Dr. Dieckhof, instituted experiments on geese. After the birds had been forty-eight hours without food, they were fed with oats. In each experiment two birds were required. In one the vagus was divided on both sides, while the other was left uninjured for the sake of comparison. After the death of the first, which took place in the space of five days, the second was killed. In the latter the crop was generally empty; in the former it was always fully distended with oats, and some grains were contained in the muscular gizzard, and these were in part crushed. The fluid in the stomach was acid, but less so than in the other uninjured animal. Hence we may conclude that digestion is for the most part, but not entirely, checked by the division of the nervi vagi. Tiedemann states, it is true, that after both vagi had been divided in a dog, neither the matter vomited nor the mucus secreted by the stomach was acid; and Mayer also relates that in his experiments on cats and dogs the chyme formed after the operation was not acid: yet he found the chyme acid in rabbits; and in my experiments with Dr. Dieckhof I never found the acidity absent, although it was less marked than in the sound animal. In four of the dogs in which Dr. Reid had divided the vagi nerves in the neck for the purpose of ascertaining the nature of the morbid changes produced in the lungs, unequivocal proofs were afforded, that, although lesion of the nervi vagi generally arrests digestion, yet that process may occasionally go on perfectly well, even although the cut ends of the nerves are kept far apart. One dog which lived twelve days after the operation, was rapidly gaining flesh and strength; and when he was killed, the lacteals and the thoracic duct were found full of milky chyle. In two other dogs, food taken after the operation was vomited in a half-digested state, and was found to permanently redden litmus paper; and the lacteals were filled with chyle in one of these dogs also, as well as in a fourth by which milk that was given to it was vomited in a coagulated state.*

Dr. Wilson Philip has asserted that, after the experiment of dividing the nervi vagi has been performed, the digestive action may be restored by means of an electrical current transmitted through the vagus nerve, one pole of the battery being applied to the nerve, the other to a piece of tin foil laid over the epigastric region. The experiments were repeated by Breschet and Vavasseur. They found that simple division of the nervi vagi had not the effect of completely arresting the digestive process, although this was the result, when, in place of the nerve being merely divided, a portion of it was removed. (*Froriep's Notiz.* vi. 261.) I must remark, however, that when a nerve is divided, whether a portion is cut out or not, it is paralysed, and remains so for a very long time. Breschet and Vavasseur in the next place affirmed, that by directing an electric current through the divided nerves, digestion could be entirely restored; in which effect they attribute some share to the increased muscular action of the stomach. Breschet and Edwards (*Arch. Gén. de Méd.* 1828,) have, however, since modified these views: as the results of their later experiments, they announce that division of the nervi vagi retards chymification, but does not completely arrest it; that this retardation of the process depends on the paralysis of the œsophagus, which is likewise the cause of the vomiting that occurs after the operation; and that the restoration of the digestive process by means of the electric current, is not owing to the electricity itself, but to the irritation of the vagus nerve produced by it, since mechanical irritation of the lower portion of the nerve has the same effect in restoring the digestive process, which it does by re-exciting the motions of the stomach. But as I have frequently stated, on the ground of experiment, the motions of the stomach cannot be in the slightest degree affected by irritation of the nervus vagus. If MM. Breschet and Edwards had only continued their experiments longer, they would perhaps have perceived that neither the electric nor mechanical stimulus had any remarkable effect on the digestive process; that the animals remained in the same state, whether these stimuli were applied or not, as appeared to be the case in the following experiments of Dr. Dieckhof and myself:—

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* Dr. J. Reid's Experimental Investigation into the function of the eighth pair of nerves. Edin. Med. and Surg. Journ. vol. 51, p. 310, et seq., and American Edit., in volume form.

In each experiment we took three rabbits, kept them without food for forty-eight hours, and then fed them with cabbage. One was left uninjured; in the second, the two nervi vagi were simply divided; and in the third, the nerves were in like manner divided, but in it a galvanic current was directed through the nerves in the way directed by Dr. W. Philip, and maintained for seven or eight hours. As soon as either the third or the second rabbit died, the other two were also killed. In every experiment we found that the sound rabbit had digested perfectly; all that remained of the food was the insoluble portion, which was nearly dry; in the two others the food in the stomach was in nearly exactly the same state in both: in one instance the food of the rabbit in which the galvanism had been applied was somewhat less digested; in many cases the state of the food in the two was exactly the same, and in several instances it was in the galvanised rabbit perhaps somewhat more digested than in the other, but the difference was scarcely to be noticed.*

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* Dieckhof de actione quam nervus vagus in digestionem ciborum exerceat. Berol. 1835.

Matteuci affirms that he has been able to effect the artificial digestion of meat, with chloride of sodium and the simultaneous influence of electricity. Grounding his opinion on the experiments of Wilson Philip, Matteuci imagines the acid reaction of the stomach to be produced by a positive electric state of the viscus. To prove this, he took a piece of boiled meat, poured water over it, and added some common salt and carbonate of soda; he kept the mixture a long time at a proper temperature, constantly triturating it until it was reduced to a pulpy mass like that produced by mastication. He then introduced the pulp thus prepared into a bladder moistened with solution of common salt, and connected with the bladder the poles of a galvanic battery of eighteen or twenty pairs of plates. The result was, he states, that along the walls of the bladder, and especially around the positive wire, a layer of a whitish dense substance full of bubbles of oxygen gas was formed; that this substance was flaky, and after being dissolved in water coagulated when heated. I had, during a very long period, tried in vain to dissolve portions of meat in acids or chloride of sodium with the aid of an electric current; the results obtained by M. Matteuci could not, therefore, but appear very improbable to me. I have, in conjunction with Dr. Dieckhof, repeated the experiment; we introduced into different bladders two portions of the same pulp, consisting of pieces of meat with common salt and carbonate of soda; one bladder only was subjected to galvanism, the other was left undisturbed. At the conclusion of the experiment, no kind of difference could be detected between the fluids contained in the two bladders.

c. Of the changes which the chyme undergoes in the small intestines.—We recur to the excellent researches of Tiedemann and Gmelin, for they contain all that we know with certainty relative to the subsequent changes which the chyme undergoes. In the duodenum the chyme is acid. The stimulus which it exerts on the coats of the intestine, and which is propagated along the ductus choledochus and its branches generally, gives rise to the effusion of bile and pancreatic juice: Tiedemann has found the gall-bladder almost empty in animals in which digestion was going on. After gelatin had been given as food, it could still be detected in the contents of the small intestine; when butter had been given, the contents of the small intestine contained a fatty matter; casein was detected, though not distinctly, when the animal had been fed with cheese; and some remains of starch were found, though not always; the starch was in greater part converted into gum of starch. When the food had consisted of milk, cheesy clots were met with in the first half of the small intestine. A dog having been fed with some bones, small fragments of the bone were found in the upper half of the small intestine; in the lower half, abundance of phosphate of lime, with a small quantity of carbonate of lime. In horses which had been fed on oats, the upper half of the small intestine still contained starch; but in the middle and lower part of the intestine this substance had no longer its characteristic properties.

Tiedemann and Gmelin found the contents of the upper half of the small intestines acid, though less strongly so than the matters in the stomach; the acidity gradually diminished in approaching the cæcum, and at the extremity of the ileum could usually be no longer detected. The experiments of these observers leave undetermined the cause of the chyme losing its acidity,—whether it is owing to its acid being neutralised by the alkaline carbonate of the bile, or to the lower part of the small intestine pouring out an alkaline secretion: or whether, in consequence of decomposition commencing, ammonia is developed and neutralises the acid; or lastly, whether the acid part of the chyme is absorbed from the intestines, in which case it must lose its acidity in its course through the lacteals and mesenteric gland, since the chyle itself is certainly alkaline.

The principal animal matters composing the chyme of the small intestines are:—

1. Albumen; of which the quantity decreases in the lower part of the small intestines, in consequence of the absorption of the chyme by the lacteals.

2. Casein; which likewise diminishes in quantity as we approach the cæcum.

Respecting these two substances, it cannot be determined how large a portion of them is owing to digestion, and how much to the secretions poured into the digestive canal,—for instance, to the pancreatic secretion. Tiedemann and Gmelin think it possible that the casein of the pancreatic secretion containing a large proportion of nitrogen, yields a portion of this element to different ingredients of the alimentary substances, which contain less nitrogen, so as to reduce itself to their standard in this respect, and to convert them into albumen.

3. An azotized substance precipitated by muriate of tin. (Salivin and osmazome.) Its quantity diminishes in the course of the passage of the ingesta through the small intestines.

4. A matter to which chlorine imparts a red colour,—derived probably from the pancreatic secretion since it cannot be detected in the stomach; and being found in the small intestines after the bile duct has been tied, cannot be derived from the bile. It is not found in the matter of the excrement.

5. Substances soluble in alcohol, and insoluble in water. Fatty matter, stearine, and the colouring and resinous matters of the bile.

The substances here enumerated do not differ in their nature from those which Tiedemann and Gmelin found in the contents of the intestines in animals which had been kept without food. With the exception, therefore, of the abundant albumen, the product of the food, they are most probably derived from the secretions poured into the canal, particularly the pancreatic secretion, which contains albumen, casein, and a matter which is reddened by the action of chlorine.

Influence of the biliary secretion on the chyme.—Dr. Beaumont has investigated, by experiment, the effect of mixing bile with the chyme out of the body. On adding some bile of the ox to chyme obtained from the stomach of St. Martin, a turbid yellowish-white fluid, or rather delicate white coagula were formed, which, after standing some little time, separated into a bright yellow flaky precipitate, and a turbid milky fluid. For the sake of comparison, Dr. Beaumont mixed, in another experiment, bile and dilute muriatic acid, of each one drachm, with two ounces of water; and a similar turbidity was the result; but the sediment which formed was gelatinous and of a deep green colour, and the supernatant fluid of a bluish-green colour, and not milky as in the former case.

Purkinje has observed that the addition of even a small quantity of bile to the digestive fluid, puts a stop to artificial digestion. Tiedemann and Gmelin's researches afford no satisfactory information relative to the office of the bile in the process of chymification. The acids of the chyme coagulate the mucus of the bile and precipitate it, together with a great part of the colouring matter. The cholesterine, likewise, is precipitated, and is obtained by digesting in alcohol that part of the contents of the intestine which is insoluble in water. The margaric acid found in the contents of the small intestines, is believed by Tiedemann and Gmelin to be likewise derived from the bile. The resin of the bile contained in that portion of the intestinal contents which is insoluble in water, appeared to them to be an excrementitious substance having no influence in the changes which the food undergoes, and forming a principal ingredient in the fæcal matter. The opinion of Werner,* generally adopted by physiologists—that the chyle is precipitated by the bile in the form of flocculi —was found by Tiedemann and Gmelin to be groundless. The mixture of bile with the fluid contents of the stomach, produced no other precipitates than resulted from the addition of an acid to bile. The flocculi in the small intestine, which are supposed to be flakes of chyle, are nothing more than shreds of mucus, and were present even when the *ductus choledochus communis* had been tied. The chyle which is absorbed by the lacteals, is fluid. Autenrieth and Sir A. Cooper speak of the chyle as a tolerably consistent matter, lying between the villi, and coagulating when exposed to the air. (See also *Abernethy's Physiol. Lectures*, p. 189.) This matter is, however, according to Tiedemann and Gmelin, merely mucus; so that the statement that it coagulates must be erroneous. The matters in the bile which have a share in producing the necessary changes in the chyme, are probably the picromel, the osmazome, the matter similar to gliadin, and the cholic acid, since it appears from the investigations of Tiedemann and Gmelin that they do not exist in the excrement. It is not probable that the sole office of the bile, in addition to the elimination of the resin and colouring matter, which are excrementitious substances, is to neutralise the acid of the chyme, and thus to prepare the latter for the change which it undergoes in the lacteals, where, in the state of chyle, it becomes alkaline. Those of its essential components which do not form part of the excrement, either contribute to complete the solution of the chyme, which was

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* Exp. circa modum, quo chymus in chylum mutatur, Diss. Inaug. præs. Autenrieth. Tub. 1800.

Haller's opinion; or they must serve to effect the conversion of the chyme into the chyle,—that is to say, the production of albumen from the food, as Prout supposes. The chyle taken from the lacteals contains, with the exception of albumen, none of the animal matters which Tiedemann and Gmelin detected in the intestines, nor those soluble components of the bile which do not form part of the excrement; all that the chyle contains in place of these matters is albumen.

Effects of ligature of the bile duct.—Sir B. Brodie (*Quarterly Journ. of Sc. and Arts*, 1823,) has endeavoured to ascertain the degree in which the bile contributes to the process of chylification, by applying a ligature to the ductus choledochus. Jaundice was a consequence of the operation, but this sometimes disappeared after a time; and then it was found that an effusion of lymph had taken place at the seat of the ligature, and had reunited the divided portions of the duct. As to the effect of the operation on digestion, Sir B. Brodie states that the process in the stomach was unaffected, but that chyle was no longer formed from the chyme; that neither the lacteals nor the thoracic duct contained any white chyle.

Tiedemann and Gmelin have rendered valuable service to physiology by the experiments (ten in number) which they have performed to ascertain the correctness of Brodie's statement. The results which they obtained are in accordance for the most part with those of the last named gentleman. After an interval of from thirteen to twenty-six days, the canal was found to be restored. The colouring matter of the bile was detected in the blood and urine, and the lymphatics of the liver were yellow. In the experiments of Tiedemann and Gmelin, as in those of Brodie, digestion went on uninterruptedly. The contents of the small intestines also did not differ essentially from what they are under ordinary circumstances. In all Tiedemann and Gmelin's experiments, the contents of the large intestines had a much more fetid and disagreeable odour than ordinary (while Leuret and Lassaigne stated that they had a strong odour and insipid savour, not the usual disagreeable odour and savour), and the excrements were white. In dogs which had been fed after the operation, the lacteals of the small intestine contained a clear transparent fluid, just as in the dogs which had not taken food; while in dogs in which the ductus choledochus has not been tied, the contents of the lacteals are milky. The fluid of the thoracic duct was generally redder than ordinary, and yielded a larger and redder coagulum in dogs in which the bile duct had been tied, than in those in which the operation had not been performed: the serum in the former was yellow and turbid; in the latter milky. The nature of the fluid in the thoracic duct does not, however, prove much in reference to the question; for the lymph from other parts of the body is also coagulable; and in animals kept without food, the lymph continues to afford a coagulum for a very long time, as Collard de Martigny has shown, and the lacteals in such animals likewise carry lymph. It is, however, a very important fact that, after the ductus choledochus has been tied, although the animals are fed, the chyle is transparent; while in the natural state it is milky. Tiedemann and Gmelin, indeed, say, the white milky colour of the chyle is known to be owing to the presence of particles of fat. Still this difference in the appearance of the chyle, after the ligature of the bile duct, deserves further consideration. The experiments of Tiedemann and Gmelin, do not prove, in a satisfactory manner, that the formation of chyle is independent of the bile. Tiedemann and Gmelin also urge as an argument in favour of their opinion, that many of the dogs lived for a considerable time after the operation,—from three to seven days. In one case, in which the jaundice remained, although the canal of the duct was restored, the animal lived twenty-six days; at the end of which time it was killed. But dogs will live about thirty-six days, although wholly deprived of food. Leuret and Lassaigne, who, with Tiedemann and Gmelin, maintain that digestion and chylification are not arrested by ligature of the *ductus choledochus*, attribute to the bile the property of dissolving the fat, of decomposing it, and forming with it a kind of soap, thus effecting its digestion. But experiments of Tiedemann and Gmelin show that bile is not capable of dissolving the smallest quantity of fatty matter, and can therefore contribute to its division and absorption only in a mechanical manner, by effecting its suspension in minute particles.

The bile seems to be a necessary stimulus for the peristaltic motions of th eintestines; for, when its flow is arrested, constipation is the result.

d. Changes which the ingesta undergo in the large intestine.— The mixture of chyme, mucus, bile, and pancreatic juice, becomes in its passage through the lower part of the small intestines more consistent and of a darker colour. The fluid parts are absorbed by the lacteals. All the solid matters, as mucus, skins of fruit, woody fibre, horny matter, and those ingredients of the bile which are excrementitious, such as the mucus, colouring matter, fatty matter, and resin, on reaching the lower extremity of the small intestine, constitute the excrement, from which, however, the fluid ingredients continue to be absorbed in its passage through the large intestine.

Tiedemann and Gmelin regard the acid secretion of the cæcum as a second solvent of the animal matter. This second digestion would appear to take place principally in the herbivora, in which the cæcum is especially large; and it is very probable that in the horse, in which the food passes the pylorus in a far less perfectly dissolved state than in man, the digestive process must be continued in the very large cæcum and colon. Schultz follows Tiedemann and Gmelin in admitting that digestion is renewed in the cæcum, but supposes that the gastric and cæcal digestions antagonise each other; that the first is performed during the day, the latter during the night, and that the first commence when the latter ceases. Each meal ought, according to this hypothesis, to pass through the whole intestinal canal in twenty-four hours, which is not regularly the case. In Tiedemann's experiments of a ligature of the ductus choledochus, the excrements did not appear white until two days after the operation. Schultz imagines, moreover, that while the digestion is going on in the large intestine, the entrance into it is closed, that bile collects in the lower part of the small intestine, and does not enter the large intestine till chymification in the latter is completed; and that it then flows into the cæcum, and neutralises the chyme.

Gaseous matters in the intestines.—Air is swallowed with the food, and is in the stomach partly converted into carbonic acid; but, in addition to this, a development of gas takes place during digestion in the whole extent of the alimentary canal. Its nature depends partly on the kind of food, and partly on the state of the digestive organs. In affections of the nervous system, the evolution of gas is often very abundant; it is sometimes devoid of smell, but generally has the odour of sulphuretted hydrogen, and is frequently inflammable. It may consist of hydrogen, carburretted hydrogen, or sulphuretted hydrogen. The analysis of the gases contained in the intestines of executed criminals afforded Magendie and Chevreul the following results:—

The gas in the small intestine consisted, in three individuals, of

Carbonic acid gas,	24·39	40·00	25·00
Hydrogen,	55·53	51·15	8·40
Nitrogen,	20·08	8·85	66·60
	100·00	100·00	100·00

	The gas in the colon consisted of		That in the rectum of
Carbonic acid,	43·50	70·00	42·86
Carburetted hydrogen, with traces of sulphuretted hydrogen,	5·47	—	—
Hydrogen, and carburetted hydrogen,	—	11·60	—
Pure carburetted hydrogen,	—	—	11·18
Nitrogen,	51·03	18·40	45·96
	100·00	100·00	100·00

I refer to the work of Berzelius (*Chimie Animale*, p. 268,) for an account of the composition of the excrement. Human fæces, of consistence sufficient to form a coherent mass, are, according to his analysis, formed of

Water,			75·3
Matters soluble in water,	Bile,	0·9	5·7
	Albumen,	0·9	
	Peculiar extractive,	2·7	
	Salts,	1·2	
In the residue of the food,			7·0
Insoluble matters which are added in the intestinal canal,—mucus, biliary, resin, fat, and a peculiar animal matter,			14·0
			102·0

In birds and reptiles the urine and fæces are both received into the cloaca.

CHAPTER VI.

OF CHYLIFICATION.

During the passage of the chyme through the whole tract of the intestinal canal, its completely digested parts are taken up by the lacteals. The mode in which this absorption is effected, has been already discussed in the Section on the lymph and lymphatic vessels. The observation there adduced, that the serum of the blood of kittens which are sucking is sometimes perfectly white, would make it appear probable that in those cases the globules of the milk did really gain entrance into the lacteals. But this state of the blood is not constant under the circumstances indicated, and it might arise from the same cause as the similar appearance of the blood sometimes presents in adults, when the chyle has not undergone the change of sanguification, or when it contains a greater quantity of fatty particles. The coats of the radicle lacteals must, it is clear, have invisible pores, since they absorb fluids; but these pores, even if they allow the passage of globules, cannot be larger than the chyle globules themselves, which Prevost and Dumas state to have a diameter of $\frac{1}{7500}$ of an inch, and which, according to my measurement, are for the most part (in the calf, goat, and dog) half or one-third the size of the red particles of the blood of a mammiferous animal. For, if the size of the pores were more considerable, larger particles of the chyme would enter the lacteals, which is not observed to be the case; once only,—namely, in a rabbit,—I found the smaller number of the chyle globules larger than the particles of the blood; and once also, namely, in the cat, I found some of them equal in size to the blood particles, but here also the greater number were smaller. The larger particles which I saw in the chyle of the rabbit could not, however, have entered through the coats of the intestinal villi; for openings which would allow their passage, must be visible. The large openings called Lieberkühn's follicles, which are distributed in such number over the surface of the mucous membrane between the villi, and which are so distinctly visible, being nearly twelve times larger than the red particles of the blood, are mere crypts, and appear to be in no way connected with lacteal absorption.

The chyle is the fluid absorbed from the intestines by the lacteals during digestion, and differs from the lymph which those vessels contain at other times, and from the contents of the lymphatics of other parts of the body, in being of a white or milky colour. In birds it is usually not milky, but transparent, and it is likewise not very turbid in most of the herbivorous Mammalia; but in the Carnivora, and even in the young of the Herbivora while they are nourished with milk, it is always more or less turbid and whitish. The colour is owing to the presence of globules, the size of which I have stated above. The chyle is very rarely red; it has been seen of this colour only in very few instances, as, for example, in the thoracic duct of the horse: in the animals in which I have examined it—the calf, goat, dog, cat, and rabbit—the chyle has never been otherwise than white, even in the thoracic duct. Chyle has an alkaline reaction, and its smell has by some been compared to that of human semen.

Chyle coagulates spontaneously within a short time after its removal from the vessels. Reuss and Emmert agree with Tiedemann and Gmelin in stating, that the coagulability of the chyle increases with its progress through the absorbent system; that the chyle of the lacteals does not coagulate, and indeed has rarely the property of coagulating spontaneously even when it has traversed the mesenteric glands. The chyle of the thoracic duct coagulates, like the lymph, in about ten minutes after it is taken from the vessel, and separates into coagulum and serum. The coagulum is the fibrin of the chyle, mixed with some of the globules. The serum is a solution of albumen, with another portion of the globules suspended. At the same time, a creamy matter, which consists of fatty particles, collects on the surface.

The coagulum of the chyle of the thoracic duct, after exposure to the air, often becomes much more red than it was previously. On comparing the chyle taken from the lacteals themselves, with that from the *cysterna chyli,* and again with chyle from the middle and upper portions of the thoracic duct, Emmert (*Scherer's Journal der Chemie,* v. p. 164, 691,) found that the action of the air produced little change on the milk-white chyle of the lacteals, while that of the *receptaculum chyli* acquired a slightly red tint, and yielded a slight coagulum. The chyle again from the upper part of the thoracic duct assumed a tint approaching very nearly that of arterial blood, and separated into serum and a kind of crassamentum, which was more solid and larger than that of chyle taken from other parts of the lacteal system. The serum of the chyle from the receptaculum and the great lacteal trunks was less limpid, was turbid, and contained a great number of whitish-yellow globules. The serum of the chyle of the thoracic duct was transparent, and to the naked eye appeared to contain no globules. The chyle which Emmert obtained from the middle portion of the thoracic duct, contained somewhat more animal matter than that which he took from the upper part of the duct; this may be accounted for, perhaps, by the circumstance that the upper part of the thoracic duct would contain, in addition to the chyle, a relatively larger proportion of the lymph from other parts of the body, which is a much more diluted fluid. (See also *Reil's Archiv.* viii. 146.)

Differences in the chyle arising from variety of food.—Magendie states, that chyle derived from food which contains little or no fat, is not so milky, but has a more opaline aspect; and that when it separates into coagulum and serum, only a little of the cream-like matter rises to the surface. On the contrary, the chyle, he says, which is formed from food of a fatty nature, whether it be animal or vegetable, is white, and separates into three substances,—a fibrinous coagulum, serum, and a creamy stratum on the surface of the fluid, which contains the fatty ingredients. Dr. Marcet (*Medico-Chirurg. Trans.* 1815,) has observed, that chyle from vegetable food putrefies more slowly than chyle from animal food, and contains more carbon; and that the chyle from animal substances is always milky and affords an oily scum, which does not form on the more transparent chyle derived from the vegetable diet.

Tiedemann and Gmelin observed that the chyle of sheep fed on grass or straw, was very slightly turbid,—indeed, was nearly clear. The turbidity was very slight, likewise, in the chyle of dogs which had been fed upon liquid albumen, fibrin, gelatin, cheese, starch, and gluten, as well as in that of a horse fed with starch. The chyle of sheep which had eaten oats, was moderately turbid; while the chyle of dogs, of which the food had consisted of coagulated albumen, milk, bone, or beef, or that of horses fed upon oats, was very milky. But the whiteness and opacity were most marked in dogs fed on butter.

Nature of the chyle globules, and cause of its white colour.—Tiedemann and Gmelin,—who, on account of the accuracy with which their experiments were performed, and of their having brought both chemistry and anatomical physiology to their aid in conducting them, are looked upon as the highest authorities in every question connected with the subject of digestion,—declare (*Recherches sur la Digestion*, Part ii. p. 72,) that the facts which they observed prove indubitably that the milkiness of the chyle is owing to its containing fatty matter suspended in a state of fine division. When the chyle coagulates, a small portion of the fat becomes included in the clot, while the greater part remains suspended in the serum, to the surface of which it sometimes rises like a cream. From the clot they were frequently able to extract a yellowish-brown fat by means of boiling alcohol; and on agitating the serum with ether freed from alcohol, it gradually became transparent, and the ether when evaporated yielded a fatty substance, partly solid and partly fluid (a mixture of stearine and elaine), the quantity of which was proportionate to the degree of turbidity of the serum. These facts led them to the conclusion that the fat of the body is derived directly from the food, and that in the chyle at least it is not in the state of solution, but merely of minute division, and in this they were further confirmed by the results of their observations above detailed relative to the effect of difference of food on the appearance of the chyle. Ligature of the ductus choledochus caused the chyle to be less turbid; and Tiedemann and Gmelin believe that this may be accounted for on the supposition that the minute division of the fatty matter and its suspension in the watery fluid are effected by the bile.

The chyle, however, does not appear to be a mere solution of animal matter, containing no other globules than those of fat. On treating the milky serum of chyle of the cat with ether freed from alcohol, it gradually became more transparent; but there still remained a turbid matter at the bottom of the watch-glass, in which I could, by the use of the microscope, distinguish globules. I have, too, examined with the microscope the milky chyle with which I found the lacteals and thoracic duct of a dog filled, on killing him five hours after he had taken food, consisting of bread, milk, and some butter. In a drop of this chyle I saw numerous globules of oil, very unequal in size and quite transparent; but the greater part of the globules were of quite another kind, namely, whitish, not transparent, and very small, about half or two-thirds the size of the particles of the blood of the dog; a difference which I had previously remarked in the calf. These minute globules, which are smaller than those which I and Dr. H. Nasse observed in human lymph, and are less regular in form than the red particles of the blood, are excessively numerous, and are evidently the cause of the white colour of the chyle. Having diluted a small quantity of the chyle with water, that the globules might be seen more distinctly by being less closely aggregated together, I watched its coagulation under the microscope, and could perceive that the change did not consist in the aggregation of the globules, but that, exactly as in the case of the lymph or blood, the delicate pellicle or clot which formed was constituted in great part by a transparent substance which connected together the globules, even though these were widely separated. But in addition to the delicate pellicles which were thus evidently owing to the coagulation of animal matter previously in solution, there formed here and there in the drops of chyle small islets of nearly perfectly transparent fat: I am unable to say whether these masses of fat were produced by the aggregation and cooling of the globules of oily matter. The chyle has hitherto been made very little the subject of microscopic examination. It would be especially desirable to know in what relation the globules of the chyle stand to the red particles of the blood; whether the latter bodies are formed from the globules of the chyle, or whether the smaller bodies observed by Sir E. Home in human blood, and by myself in the blood of frogs and birds, are identical with the globules of the chyle. The form of the chyle globules in animals, of which the red particles of the blood are large and elliptical, should be ascertained; which could be done only in the larger reptiles, where the thoracic duct can be more easily found, or in fishes. Rudolphi mentions that Leuret and Lassaigne have observed the globules of the chyle in birds to be round, although the particles of the blood are oval; but the French observers here spoke not of chyle globules, but of the particles of chyme taken from the intestinal canal.

The source of the red colour of the chyle has likewise been very fully investigated by Tiedemann and Gmelin. They found the red colour of the chyle generally more marked in horses than in dogs, and even more so in the latter animals than in sheep. In dogs it was more distinct when the food had consisted of liquid albumen, butter, milk, bone, meat, or bread and milk. The chyle was white, and the red colour of the coagulum very slight, when the food had consisted of fibrin, gelatin, soft cheese, starch and butter, or gluten. And neither chyle nor clot was at all red, if the dog had eaten coagulated albumen; nor are they so, according to my own observation, after a meal of bread, milk, and butter. The chyle was likewise devoid of the red tint in dogs killed while fasting, or after they had taken food consisting of starch, milk, raw or boiled beef, beef and wheaten bread, or liquid albumen and spelt-bread; and in cats which had been fed with bread and milk, or boiled beef.

The fluid of the thoracic duct in horses killed while fasting, was of a darker red colour than in horses which had had a feed of oats. The chyle of sheep to which only a little hay or straw had been given, was white, with a tinge of red; that of sheep fed with oats, was quite white. From the last-mentioned facts, the experimenters inferred that the chyle contains less red colouring matter, the more nourishing the food which the animal has taken; and that the red colouring matter of the blood is not generated immediately by the digestive process. The red fluid conveyed into the chyle by the absorbents of the spleen more especially must, they observe, give a less marked tinge to the chyle when the matter absorbed from the intestines is more abundant.

In a horse fed with oats, the chyle in the lacteals which had not passed through the mesenteric glands, was white; did not become red on exposure to the air, and yielded a white clot. The chyle taken from the lacteals of the mesentery after they had passed through the mesenteric glands, and that of the thoracic duct, were of a light red colour; the lymph from absorbent vessels of the large intestine was pale yellow, and yielded a white coagulum; that of the absorbents of the pelvis was red, and its clot was of a darker red than that of the chyle of the thoracic duct. From these facts, which agree with the results of Emmert's experiments, Tiedemann and Gmelin draw the conclusion that the red colour of the chyle is imparted to it by the mesenteric glands, and by the lymph of other absorbent glands, and of the spleen, being derived from the blood circulating in the capillaries of these several parts; and they remark that the circumstance of its being changed to green by the action of hydro-sulphuric acid, demonstrates that it is identical with the red colouring matter of the blood.

Hewson* first observed that the lymph of the spleen resembles diluted red wine in colour, and contains red globules. Tiedemann and Gmelin observed the red colour, as well when the animals had had food as when they had been fasting before death. Fohmann (*Saugadersyst. der Fische*, p. 45,) also has seen the lymph of the spleen red in rays opened during life, and maintains that the colour is more distinct during digestion, and likewise after long fasting, when it is also perceptible in the lymph of the liver. Rudolphi, on the other hand, says that the lymphatics of the spleen are usually as white as those of the liver and other organs, and that those of other organs also sometimes contain a bloody fluid. I must, however, remark that the contents of no other absorbents than those of the intestinal canal are ever white; and that in some few instances, in which I examined the lymph of the spleen in oxen just slaughtered, I found it in some of the large lymphatics of the colour of dilute red wine. Seiler observed a red tinge in a few instances in some of the lymphatics running on the spleen in horses; but in most cases it was absent; and in oxen, asses, sheep, swine, and dogs, the lymph of the spleen was never coloured. The observations of Tiedemann and Gmelin prove distinctly, that the red colour of the chyle and lymph is owing to the presence of some of the cruorin of the blood; but it is not yet known whether this red colouring matter is in solution, or attached to the peculiar globules of the chyle and lymph, Tiedemann and Gmelin having frequently seen the serum of chyle of a red tint.

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* Op. Posth. Ed. Lugd. Batav. 1785.—Experimental Inquiries. London, 1777.

The serum of chyle is, however, rarely quite transparent, and always contains globules; and Emmert, indeed, states that he saw red globules in the water in which he agitated the red coagulum of chyle. Hewson also saw red corpuscules in the lymph of the spleen. Schultz (*Syst. d. Circulation*) and Gurlt (*Physiol. d. Haussäugethiere*) state, that they have found in the chyle, in addition to the proper globules of that fluid, a few blood corpuscules; and hence infer that the reddish colour of the chyle is due to the presence of such red particles, of which they suppose the formation to begin in the chyle.

Fibrin of the chyle,—its source.—The firmness of the coagulum of the chyle is different in different animals. The proportion of the moist and dried coagulum in the horse, dog, and sheep, is stated as follows by Tiedemann and Gmelin:—In 100 parts of chyle

	of fresh coagulum	of dry coagulum
Of the horse, there were	from 1.06 to 5.65	from 0.19 to 1.75
Of the dog	1.36 to 5.77	0.17 to 6.56
Of the sheep	2.56 to 4.75	0.24 to 0.82

The contents of the thoracic duct coagulated more perfectly when the animals were killed while fasting, than when they had taken a meal a short time previously; and the amount of fresh and dry coagulum was greater in the former case. The dry coagulum of the chyle of horses killed while fasting, amounted to from 1.00 to 1.75; that of horses which had lately taken food, from 0.19 to 0.78 per cent.

Tiedemann and Gmelin have moreover confirmed Emmert's observation, that the proportion of fibrin in the chyle increases with the progress of this fluid towards the thoracic duct. In a horse which recently had a feed of oats, the chyle of the lacteals which had not passed through the mesenteric glands, did not coagulate; while 100 parts of the chyle of the lacteals which had passed through those glands, afforded 0.37 of dry coagulum; the same quantity of the chyle of the thoracic duct 0.19, and the same quantity of the lymph of the pelvis 0.13.

On the above facts Tiedemann and Gmelin ground their opinion that the fibrin of the chyle is not derived immediately from the food, but is formed in the blood and poured into the chyle and lymph by the glands of the absorbent system, and by the spleen. And since the chyle of the lacteals that had passed through the mesenteric glands contained more fibrin than the lymph of the absorbents of the pelvis, they conclude that more fibrin is added to the chyle by the mesenteric glands than by the glands with which the lymphatics of the pelvis communicate. However, the opinion that fibrin is thus added to the chyle is as difficult to prove as the opposite hypothesis, that the albumen of the chyle itself is converted into fibrin. To determine the correctness of either, it would be necessary to ascertain by a great number of experiments the quantity of solid ingredients, and particularly of albumen, in the serum of the fluid contained in different parts of the absorbent system. If, for example, it were found that the serum of the chyle of the thoracic duct after the separation of the fibrin contained less albumen than the serum of the lymph of the extremities, and of the chyle of the lacteals, it would be certain that albumen is converted into fibrin in the absorbent system, since it would then appear that the albumen diminished in quantity while the quantity of the fibrin increased. The results obtained by Gmelin and Tiedemann, relative to the proportion of solid contents in the serum, were, however, only contradictory. The amount of the solid substances dissolved in the serum varied from 2.4 to 8.7 per cent. In the horse which had been fed with oats,

The serum of the chyle of the lacteal contained of solid ingredients	4.9 per cent.
" " thoracic duct	3.04
" " lymph of the pelvic lymphatics .	3.1

In the horse which was killed while fasting, on the contrary,

The serum of the contents of the thoracic duct contained of solid ingredients	4.7 per cent.
The serum of lymph from the lumbar plexus of lymphatics . .	3.7

In whatever the change in the chyle consists,—whether in the addition of new matter, or in the conversion of one of its ingredients into another substance,—it must evidently be effected by the coats of the lacteal and lymphatic vessels, both those which run a distinct course, and those convoluted or interlaced lymphatics of which the absorbent glands (see page 280,) are formed.

The coats of the absorbents being traversed by capillary blood-vessels, it is possible that the fibrin, as well as the colouring matter of the blood, may permeate the membranous coats of the vessels and enter the chyle: and on account of the greater surface afforded in the mesenteric glands by the convoluted and reticulated vessels of which they are formed, this would take place to a greater extent in them than in other parts of the lacteal system. But the red particles themselves cannot in this way enter the chyle from the blood.*

The *analysis of the serum of the chyle* by Gmelin showed that the same salts exist in it as are met with in the intestinal canal. The following are the solid ingredients of the serum of the chyle of the horse, according to that chemist:—

Albumen	55.25
Osmazome, with acetate of soda, and chloride of sodium (the most abundant saline ingredient), which was crystallised in octohedrons, probably from containing some animal matter	16.02
A matter soluble in water and insoluble in alcohol, and resembling salivary extractive matter, with carbonate and a very small quantity of phosphate of soda	2.76
Brown fatty matter	15.47
Yellow fatty matter	6.35
Carbonate and some phosphate of lime obtained by calcination of the albumen	2.76
	98.61

Tiedemann and Gmelin found no traces of the substances used as food in an unaltered state in the chyle; they observed merely that, when the animal had taken butter, the chyle contained an abundance of fatty matter, and in the chyle of one dog which had taken starch they detected sugar.

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* On the very doubtful hypothesis, that the chyle is poured directly into minute veins in the mesenteric glands, as well as concerning the supposed connection of the veins and absorbents, see page 274.

Comparison of the chyle and lymph.—Both chyle and lymph contain globules; but those of the transparent lymph are very few in number, while those of the chyle are so numerous as to give it a milky appearance. They both contain fibrin, which likewise, however, seems to be contained in smaller quantity in the lymph; for Tiedemann and Gmelin found that 100 parts of the chyle of the lacteals which had traversed the mesenteric glands in a horse previously fed with oats, yielded 0.37 of dry coagulum; while the same quantity of lymph from the pelvis afforded only 0.13. This great apparent difference may, however, be owing to a portion of the numerous globules of the chyle being included with the fibrin in the coagulum. The fatty matter which is not perceived in the lymph, but is contained in so large a quantity in the chyle, giving rise to the cream-like pellicle which forms on its surface, constitutes another point of difference. The saline matters appear to be about the same in both.

Comparison of the chyle with the blood.—The chyle, as it is obtained from the thoracic duct, differs from the blood,—

1. In its globules being insoluble in water, while the red particles of the blood, with the exception of their nucleus, are readily soluble in that fluid.

2. In its wanting the red colouring matter (though this difference is not constant).

3. In the form and size of its globules.

4. In its alkalinity, which was noticed by Emmert, Vauquelin, and Brande, being, according to Tiedemann and Gmelin, always less marked than that of the blood, and sometimes absent.

5. The proportion of solid ingredients is less in the chyle than in the blood. One thousand parts of chyle contain, according to Vauquelin, only from 50 to 90 parts of solid matter; while the proportion of solid ingredients in the blood is stated by Prevost and Dumas to be 216 parts, and by Lecanu 185 parts, in a thousand.

6. In 1000 parts of serum of the blood there are, according to Reuss and Emmert, 225, and in 1000 parts of serum of chyle only 50, parts of solid matter. From the serum of the chyle of sheep, dogs, and horses, Tiedemann and Gmelin obtained from 2.4 to 7.8 per cent. of solid matter; while Prevost and Dumas state the amount of solid ingredients in the serum of the blood of those animals, to be from 7.4 to 9.9 per cent.

7. The proportion of fibrin is much less in the chyle. Tiedemann and Gmelin obtained from the chyle of the animals just named only from 0.17 to 1.75 per cent. of dry fibrin: and, according to Reuss and Emmert, (*Scherer's Journal*, v. 164,) 1000 parts of blood of the horse contain 75 parts of (moist?) fibrin, while 1000 parts of chyle contain only 10 parts.

8. The fibrin of the chyle appears to differ somewhat from that of the blood; for Brande has observed that acetic acid dissolves but a

small part of the chylous coagulum, which in this respect resembles albumen, while fibrin of the blood is generally readily soluble in that acid.

9. Chyle contains a large quantity of fat in a free state, while the fat of the blood is wholly in a state of combination with other matters; but the coagulum of chyle likewise contains fat in a combined state.

10. The chyle, like the blood, contains iron, which it derives from the food, and conveys into the blood: but the metal appears to be in a state of much less intimate combination in the chyle than in the blood; for it can be extracted from it by means of nitric acid, and then forms a black precipitate with tincture of galls, and a blue with prussiate of potash. Even the serum of chyle afforded evidence of containing iron when it had been freed from its albumen. (*Reil's Archiv.* viii. p. 167.) Emmert, however, imagines that the iron contained in the alimentary matters in the small intestine is more highly oxidised than in the chyle, first, because fluid of the small intestine of the horse is acid; and secondly, because in the filtered fluid obtained from a horse's intestine which was filled with digested aliment, a black precipitate was produced by tincture of gall, and a blue one by prussiate of potash, immediately on the admixture of these re-agents, while in chyle the change of colour in each case takes place very slowly.

Death is ordinarily the inevitable *consequence of ligature of the thoracic duct*, ensuing, according to Duvernoy, in fifteen, according to Sir A. Cooper, in from nine to ten days; and in horses, as appears from Dupuytren's experiments, in five or six days. Sometimes the animals do not die, and in these cases we must suppose that there existed several vessels connecting the lower with the upper portion of the thoracic duct; or that there were branches connecting the thoracic duct with the vena azygos—a structure which Panizza has seen in the hog, and Wutzer and I have once observed in the human subject; or we must admit that there were two thoracic ducts, as in bir dsand tortoises.*

CHAPTER VII.

OF THE FUNCTION OF THE SPLEEN, THE SUPRA-RENAL CAPSULES, THE THYROID AND THE THYMUS GLANDS.

THESE are glands unprovided with an efferent duct; they agree in having the common function of impressing some change on the blood which circulates through them, or in yielding a lymph which plays a special part in the process of chylification and sanguification; for the venous blood and the lymph are the only matters returned by them into the general system.

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* The principal treatises on the chyle are those of Werner, De modo quo Chymus in Chylum mutatur,—Tübingæ, 1800; Horkel's Archiv. für die thierische Chemie, t. i. Heft ii.; Emmert und Reuss, Scherer's Journal, v. p. 154—691; Emmert, Reil's Archiv. viii. p. 145; Marcet, Medico-chirurg. Transact. 1815, vi. 618: Brande, Philos. Transact. 1812; Prout, Annals of Philos. xiii. p. 12, 263; Ant. Müller, Diss. exp. circa Chylum.—Heidelb. 1819; Tiedemann and Gmelin, Rech. sur la Digestion, part ii.

a. OF THE SPLEEN.

*Structure of the spleen.**—The spleen is met with only in the vertebrate classes, and in them is nearly constant. Rathke and Meckel have stated that it is absent in the cyclostomatous fishes (the Petromyzon and Ammocœtes.) There is, however, a glandular organ near the cardia of the Petromyzon marinus, which Mayer (*Froriep's Notizen*, 737,) regards as a spleen. In the Myxine, Retzius has found the spleen to be really wanting; an observation which I can confirm, and which I find to apply likewise to the allied genus Bdellostoma. With these exceptions, the spleen is universally present in the Vertebrata. In the Cetacea the organ is divided into several small masses.

In man and Mammalia the spleen lies in that fold of peritoneum which is continuous with the serous covering of the anterior and posterior surfaces of the stomach, and extends between the great curvature of the stomach, the diaphragm, and the transverse colon; and which, at the part where it connects the stomach to the transverse colon, is called great omentum. This portion of peritoneum passed originally from the spinal column in the middle line to the great curvature of the stomach, forming a mesogastrium, (See *J. Müller, in Meckel's Archiv.* 1830, p. 395,) in which the spleen was developed. The spleen, therefore, is not an organ proper to the left side of the body, of which the fellow of the opposite side is wanting; but it should be regarded as an organ originally situated in the middle line, just like the liver, which at first, when its two lobes were equal, did not belong to the right side more than to the left.

The spleen is invested by a strong fibrous membrane, which sends numerous band-like processes into its interior, so as to support the soft, pulpy, red tissue of the organ. In the red substance there are, in many animals, whitish round corpuscules, visible by the naked eye, which were first discovered by Malpighi, and of which, the existence in the human spleen has been at one time admitted, at another denied.

The corpuscules of the human spleen are described by Dupuytren and Assolant as greyish bodies, devoid of internal cavity, and measuring ⅛th of a line to 1 French line in diameter, and so soft as to take a liquid form when raised on the knife. Meckel describes them as roundish whitish bodies, ⅙th of a line to 1 line in diameter, most probably hollow, at all events very soft, and very vascular. Such soft bodies are certainly met with sometimes in the dog and in the cat, and in very rare instances in the human subject. They are the parts which Home, Heusinger, and Meckel describe to swell considerably in animals after drink is taken; an assertion, the correctness of which I doubt. I can throw no light on the nature of these bodies; they are very different from the grape-like corpuscules discovered by Malpighi in the spleen of some herbivorous quadrupeds.

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* See Müller, in the Archiv. für Anat. und Physiol. 1834, i.

I have found the Malphigian corpuscules in the hog, sheep, and ox. They are most easily examined in the hog. On an accurate examination of the corpuscules in the spleen of the hog, I found that none are isolated; that each sends out processes towards one or both sides; and that sometimes, though rarely, they are united in a line like the knots of a cord, each knot sending out other smaller threads: generally they are attached by short pedicles to fibres which are branches of other fibres, or, which is most frequent, they are sessile, and attached by a more or less broad base to the side of ramifying fibres.

By means of fine injections I ascertained that the vessels to which the corpuscules are attached, are branches of the splenic artery, and that it is more especially with the sheaths of these arteries that they are connected.

In the interior of the corpuscules there is a fluid, white, pulpy matter, which consists for the most part of irregularly globular particles, nearly all of equal size, and of about the same diameter as the red particles of the blood, though not flattened like them. Under the microscope they have the same appearance as the granules of the pulpy substance of the spleen, and are of the same size.

The red pulpy substance consists of a mass of red-brown granules, as large as the red particles of the blood, but differing from them in form, being irregularly globular, not flattened. These granules are easily separable from each other. In the mass which they form, the minute arteries ramify in tufts, and terminate in the plexus of venous canals into which all the blood of the spleen is poured, before it is carried out of the organ by the splenic vein. The anastomosing venous radicles, which are of considerable size, appear to have scarcely any distinct coats. If a portion of the pulpy substance of the spleen is examined attentively, it is seen to be everywhere perforated with small foramina, which are spaces bounded by the reticulated substance of the organ. These spaces are venous canals; on inflating them the organ acquires a cellular appearance; and if they are injected with wax, the substance of the spleen will present a great resemblance to the corpora cavernosa penis. There are no true cells in the spleen. The white corpuscules are embedded in the pulpy substance, and not contained in cells, as Malpighi supposed. A fibrous trabecular tissue intersects in all directions the very soft pulpy red substance, and affords support to the texture of the organ.

In the human spleen the Malpighian corpuscules are distinguished with great difficulty. I have recently seen them in a spleen which had been macerated. They are very firm, and much smaller than the greyish soft points sometimes seen in cut surfaces of the spleen, which have been described under the name of the Malpighian corpuscules, but are really very different from them.

Function of the spleen.—We are quite ignorant of the office of the spleen; we merely know that its importance in the economy is not great: the experiments of numerous observers have shown that it may be extirpated without any remarkable ill consequence.

All the theories which regard the spleen as essentially connected in its function with the liver, can be shown to be fallacious. No value can be accorded to the circumstance that the splenic veins join the vena portæ, and to the hypothesis, thence deduced, that the spleen prepares the blood for the secretion of the bile; for in this respect it does not differ from all the chylopoietic viscera, nor even from the inferior extremities in the lower Vertebrata and the generative organs and air-bladder of fishes.

Dobson's hypothesis, that the spleen is the receptacle for the increased quantity of blood which the system acquires from the food, and which cannot, without danger, be admitted into the blood-vessels generally, and that it regains its previous dimensions after the volume of the circulating fluid has been reduced by secretion. The premises of this theory do not appear to me to be sufficiently proved. Dobson repeated Magendie's experiment of injecting fluids into the veins of an animal, and, he says, with the same result with regard to the spleen, namely, the increase of its size.

The assertion of Defermon, (*Nouv. Biblioth. Méd.* Mars. 1824.—*Froriep's Not.* 148,) that the spleen undergoes changes of volume when certain substances are taken into the system—for example, that it becomes smaller under the influence of strychnine, camphor, and muriate of morphia—appears to me likewise to require confirmation. The function of the spleen probably consists in the production of some change, of unknown nature, in the blood which circulates through its tissue, and in thus contributing to the process of sanguification; or in the secretion of a lymph of peculiar nature, which, being mixed with the contents of the lymphatic and lacteal system coming from other parts, tends to perfect the formation of the chyle. There are no other ways than the lymphatics and veins by which any animal matter, modified by the action of the spleen, can be conveyed away from it. Tiedemann believes that the lymphatics perform this office; but whether he is correct or not is quite uncertain, and the nature of the change which the animal matter is supposed to undergo in the spleen is still less known.

The blood of the splenic vein, according to Tiedemann and Gmelin, (*Rech. sur l'Absorption.—Versuche über die Wege*, &c. p. 70,) does not differ from other venous blood; they saw it coagulate like the blood of other organs. The older physiologists, and more recently Autenrieth, (*Physiologie*, ii. 77,) maintain, however, that the blood has peculiar characters. Schultz, (*Rust's Magazin.* 1835, 327,) too, found the blood of the vena portæ of a darker tint than other venous blood, and the dark colour was most evident in animals which were fasting. Neither neutral salts nor the action of the air had the effect of rendering it of a brighter red colour; its coagulum was less firm than that of other blood, and it contained less fibrin and albumen, but more fatty matter.

Mr. Hewson (*Experimental Inquiries*) supposed that it was the office of the spleen, as well as of the lymphatic glands and thymus body, to secrete from arterial blood a fluid which, mixed with lymph, should give rise to the formation of red blood particles. This, however, cannot be true; for the red particles are formed equally well after the extirpation of the spleen. The reddish colour of the lymph of the spleen, observed by Hewson, Tiedemann and Fohmann, is not constant.

Mayer has asserted that the spleen is reproduced after extirpation. He says, that after the lapse of some years he has found in ruminating animals, in the place of the spleen, which had been removed, a body of the size of a lymphatic gland: this would be an interesting fact if it could be satisfactorily proved; which, however, is scarcely possible, for animals often have small accessory spleens (splenculi), and, besides, in the operation of extirpation a small portion of the organ might be left behind in the body. The presence or absence of the bunches of white corpuscules, above described, might aid in determining whether any substance were spleen or not.

b. Of the supra-renal Capsules.

Their structure.—The supra-renal capsules are met with in man, in Mammalia, in birds, and in a rudimentary state in reptiles, and in the sharks and rays. Retzius has described them in serpents, and sharks and rays; and Nagel has found traces of them in crocodiles, in chelonian reptiles, and in serpents. Nagel agrees with Retzius in regarding the fat body of the frog as a distinct structure from the supra-renal capsule, the true analogue of which he believes to be a line of yellow granular substance on the anterior surface of the kidneys.

The supra-renal capsules are formed of a yellow cortical substance which consists of vertical fibres, and of a dark spongy medullary portion. The only cavity in the interior of the organ is that of the vein which lies in its centre. In the cortical substance the minute arteries and veins are of uniform size, and nearly as delicate as the ordinary capillaries of other parts, and are regularly arranged in a radiated manner, running nearly parallel to each other from the surface towards the interior. There are no grounds for the belief that the supra-renal capsules are deficient in acephalous monsters more frequently than any other organs.

The function of the supra-renal capsules is unknown. The researches of Meckel and myself have shown that, in the human embryo, they are originally larger than the kidneys; and in an embryo one inch long, for example, even conceal the kidneys from view. It is not until the tenth or twelfth week that the latter organs equal the supra-renal capsules in size. In other mammiferous animals I have never found the supra-renal capsules of larger size than the kidneys at any period. They have no physiological connection with the urinary organs. In a case in which the left kidney was abnormally situated on the right side, I found the corresponding supra-renal capsule in its usual place; while in another instance, where the kidney was atrophied, the supra-renal capsule of the same side was of its natural size and structure.

c. *Of the Thyroid Body.*

Structure.—The thyroid body, or gland, appears to contain very small cells, the connection of which, as well as the proper structure of the organ, are unknown. In goître the cells become enlarged, and contain an albuminous matter. *Function* unknown.

d. *Of the Thymus Gland.*

Structure.—The thymus gland, in proportion to the size of the body, is largest in the fœtus, but continues to grow after birth, and remains of considerable size during the first year, after which it gradually diminishes until it has about the time of puberty wholly disappeared. Krause, (*Müller's Archiv.* 1837, p. 6,) however, has recently stated, that in almost all individuals of ages between 20 and 30 years, in whom he has examined the condition of the thymus, he has found it still existing, and in many instances of larger size than in young children; and in persons between 30 and 50 years of age, he has seen it still of considerable size.

In the calf, the organ consists of lobes which are divisible into smaller lobules. Each lobule is constituted of numerous secreting cells, and larger cavities or reservoirs.

In the human subject the largest lobuli do not exceed a pea in size. The essential point in the structure, therefore, as ascertained, by Sir A. Cooper, is that the small cells or cavities in the substance of the lobules communicate with other pouch-like cavities at their base, which again lead by small openings into the common reservoir. Sir A. Cooper describes a large lymphatic, which is easily injected, to be connected with each cornu of the thymus in the fœtal calf, and to terminate at the point of junction of the two jugular veins with the superior vena cava. But the connection of the lymphatics with the cavities in the gland has not been demonstrated.

The fluid of the thymus is whitish, contains microscopic white particles, and is coagulable by alcohol, mineral acids, and heat. Liquor potassæ converts it into a tenacious substance. One hundred parts contain sixteen parts of solid matter. The saline ingredients are muriate and phosphate of potash and soda, with a trace of phosphoric acid. The nature of its proximate animal components is imperfectly known. Fibrin appears not to be one of its ingredients, and this circumstance distinguishes it from lymph and chyle.

Function of the thymus.—The anatomical facts detailed by Sir A. Cooper would seem to indicate that a peculiar albuminous fluid is conveyed from the thymus gland to the veins by the lymphatics. It appears quite vain to attempt by hypothesis to explain how the organ can contribute to the formation of the blood in the fœtus and child. But every hypothesis which regards it as an organ adapted to the necessities of fœtal life, and not to those of the child, must be incorrect.

Henle has found that the acini of the glands without excretory ducts are composed of regular nucleated cells, which he supposes to have the function of effecting a chemical change in the blood circulating around them.

SECTION III.

OF SECRETION.

CHAPTER I.

Of the Secretions in General.

During the passage of the blood from the minute arteries through the capillary system of vessels into the radicles of the venous system, a part of the "liquor sanguinis," with the matters dissolved in it, is imbibed by the tissues, and by their agency undergoes a chemical change. Some of its components are extracted from it, while it receives in exchange other matters derived from the parenchyma.

The changes which the organic matter suffers in this way may be termed generally transformations or "metamorphoses." They are of three kinds:—

1. Transformation of the components of the blood into the organised substance of the different organs,—"*intus-susceptio,*" or nutrition, which will be treated of in the next section.

2. Transformation of the components of the blood on the free surface of an organ into a solid unorganised substance, which is the mode of growth of the non-vascular textures,—"*appositio.*"

We have, however, already seen, that the substance composing the non-vascular tissues is as much organised as the elementary parts of the vascular structures, and that their process of growth is essentially the same.

3. Transformation of the components of the blood into a fluid matter which escapes on the free surface of the organ,—secretion, which is the subject of the present section.

The matters separated from the blood by the action of a secreting organ are,—1. Substances which existed previously in the blood, and are merely eliminated from it: such are the urea, which is excreted by the kidneys; and the lactic acid and its salts, which are components both of the urine and of the cutaneous perspiration. These are called *excretions;* and the process of their separation from the blood, *excretion.* The excretions which are met with most generally in the animal kingdom, namely, the urine, and the fluid perspired by the skin, are in the human subject acid; but all excretions are not acid, as Berzelius formerly supposed, for the urine of some herbivorous animals is alkaline, as are also some of the excretions peculiar to several animals; for instance, the acrid matter excreted from the skin of the toad. 2. Substances which cannot be simply separated from the blood, since they do not pre-exist in it, but which, on the contrary, are newly produced from the proximate components of the blood by a chemical process; such are the bile, the semen, the milk, mucus, &c. These are called *secretions.*

These true secretions are again divisible into two series:—

a. Some either fulfil no further purpose in the animal economy by which they are formed, or at most serve for its defence by being poisonous to other animals, or attract or repel other animals by diffusing peculiar odours. Secretions of this kind may have their seat at almost any part of the surface of the animal body. As examples, we may instance the acrid secretions of many beetles, of wasps, bees, and the scorpion; the peculiar secretions of which spiders form their web, insects and spiders their cocoon, and mussels their byssus for attachment; the ink of the cuttle-fish; the castoreum of the preputial follicles of the beaver; and the secretion of the musk-bag, situated under the skin of the abdomen above the penis, and opening in front of the prepuce in the musk-deer.*

Besides their action out of the system, such secretions may have an importance in the economy of the animal which forms them, inasmuch as, being formed at the expense of the proximate components of the blood, their production must be attended with a change in its composition, and the suppression of them would, in some cases, perhaps, be equally as injurious to the system as the suppression of certain morbid discharges in the human body, which are to be regarded as means of preserving the healthy constitution of the blood. In the case of the conversion of one organic compound into another out of the body, certain elements which are not necessary to the new compound are set free; for example, during the generation of alcohol from sugar carbonic acid is disengaged. The production not merely of the cutaneous exhalation and of the urine, but also of the peculiar secretions of many animals, may be explained in a similar manner. The formation and elimination of the urea have the same relation to the production of higher organic products, as the evolution of carbonic acid has to the formation of alcohol from sugar. If morbid secretions are regarded in the same point of view, they must be distinguished into two kinds; first, those the elimination of which is absolutely necessary for the preservation of the normal constitution of the blood, and which cannot with impunity be checked, unless the process of sanguification generally has previously undergone a favourable change; and, secondly, those morbid secretions which are merely the result of local conditions, and may be arrested without danger. Accordingly, after amputation of a part which has been the seat of a copious but not cachectic suppuration, a surgeon is not justified, according to physiological principles, in instituting vicarious discharges, or in preventing the healing of the wound by the first intention.

b. Other secretions, such as the milk, bile, semen, and mucus, serve further purposes in the animal economy.

The true *secretions* are frequently alkaline, but by no means always so; and one and the same secretion (we may instance the saliva or the pancreatic fluid) often alternates from the acid to the alkaline state under the influence of trifling circumstances.

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* For an account of these and many other analogous glands, see J. Müller, De Glandul. secernent. structurâ penitiori. Lipsiæ, 1830. An abridgement of which work has recently been published in the English language, with additions, by Mr. Solly.

The formation of any one of the peculiar *secretions*, the essential proximate constituents of which do not exist in the blood itself, presupposes the operation of a special chemical apparatus, whether this be a membrane or a gland; and the destruction of the secreting apparatus must put a permanent stop to such a secretion; thus, the semen can no longer be formed after the removal of the testes, nor the milk after the extirpation of the mammary gland. Haller's assertion, (*Element. Physiol.* ii. 369,) that almost all secretions may, under the influence of disease, be formed by each and every secreting organ, is incorrect. Cases sometimes occur in which the secretion continues to be formed by the natural organ, but, not being able to escape towards the exterior on account of some obstruction, is re-absorbed into the blood, and afterwards discharged from it by exudation in other ways; but these are not instances of true vicarious secretion, and must not be thus regarded. Only the *excretions*—those matters which exist ready formed in the blood, and of which urea is an example,—can, after the destruction of the excreting organ, be eliminated from the vessels in all parts of the body by the process of exudation.

Secreting apparatus.—The apparatus for the formation of the animal secretions are either cells, such as those of the adipose tissue; plane membranes, such as the synovial and serous membranes; or organs of peculiar complex structure, the glands.

1. *Secreting cells.*—The cells of the ovary—vesiculæ Graafianæ—filled with an albuminous fluid in which the much more minute ovulum is developed, and the cells of the testes of some fishes,—of the eel and small lamprey, for example,—in which the testis has no seminal or efferent duct, as Rathke first observed, and in which the semen escaping by rupture of the cells into the abdominal cavity is evacuated from it again by a single orifice, are instances of secreting cells. Secretion by cells is, however, observed to the greatest extent in the adipose cellular tissue.

The fat is merely a deposit in the cells of the cellular tissue. It is met with in the subcutaneous cellular tissue, in the omentum, around the kidneys, in the medullary cavity and cells of bones, and less extensively in several other parts. A special structure appears not to be necessary for its secretion, since it can be deposited in all parts. It is quite unorganised, and at the temperature of the human body is even fluid or soft. The different kinds of animal fat are chiefly distinguished by the different degrees of temperature at which they become fluid or soft, and by the different proportions of stearin and elain which they contain. Human fat is among the softer kinds. The adipose matter of cold-blooded animals is still fluid at ordinary temperatures. The chemical composition of fat has been already stated. (Page 132.) The use of the fat evidently consists partly in contributing to preserve the proportions of the external form, and partly in protecting the internal parts by virtue of its being a bad conductor of caloric. But the fat may likewise be regarded as a deposit of nutriment, which during fasting, and also during wasting of the body, is again easily dissolved by being united with other animal matters, or by being converted into a saponaceous state, and having thus again entered the circulation, is applied to the formation of other organic compounds.

The nucleated cells of the fat, and their connection with the cellular tissue have been already described, (p. 110.)

The pigment cells (for example those of the choroid coat of the eye) and the nucleated globules of nervous ganglia, may also be regarded as secreting cells; the granules of pigment in the one case, and the gray nervous matter in the other, being the products of the secreting action of the cells containing them, just as the fat is of that of the cells of the adipose tissue. We shall, moreover, find that closed cells seem to play an important part in the action of many glands.

2. *Secreting membranes.*—The principal secreting membranes are the serous membranes, the mucous membranes, and the skin.

a. The serous membranes seem to be formed of fibres like those of cellular tissue (see page 110), aggregated in the same way into bundles, which are interwoven together so as to form a membrane, the free surface of which is covered by a layer of epithelium. The layer of fibres being often deficient, for example, beneath several of the serous surfaces of the brain, M. Henle (*Müller's Archiv.* 1838, p. 120,) suggests that the epithelium may be regarded as the more characteristic element of the serous membranes, to which it gives the peculiar property of their surface. There are three orders of serous membranes: 1. The synovial bursæ, of which some are subcutaneous, while others either surround or are situated beneath tendons, and give them an investment. These structures, however, being destitute of epithelium, should not, according to M. Henle's view, be classed with the serous membranes. 2. The synovial membranes of joints, which likewise invest the tendons or ligaments that pass through their cavities, and have a thick layer of epithelium like that of the skin. The synovia is an alkaline albuminous fluid, which coagulates at the boiling temperature. 3. Serous membranes which line visceral cavities.

Many persons have imagined that the serous cavities during life contain a gas, without once inquiring what kind of gas could exist there. The supposition is erroneous. The serous membranes are, during life, so filled with the viscera, that there exists no space unoccupied; and only just so much fluid is secreted by the membrane as is necessary to lubricate the contiguous surfaces, and to prevent adhesions. By the constant action of the abdominal muscles the viscera of the abdomen are kept closely pressed together, and any change of capacity which the abdominal cavity undergoes must depend on the varying fulness of the intestinal canal. Between the pleura costalis and pleura pulmonalis there is likewise during life not the smallest space; for the surface of the lungs follows constantly the movements of the thoracic parietes, on which provision, indeed, respiration depends. There is also no necessity for supposing the existence of any gaseous matter between the heart and pericardium during life, for one part of the heart is always distended with blood, while the other part is contracted; and even if a vacuum could be produced in the pericardium by the contraction of one part of the heart, it would be immediately occupied by the lungs, expanded by the external air entering through the bronchi.

There subsists between the different serous sacs such a sympathetic connection, that inflammation in one is readily communicated to the others. They become vascular by inflammation. A disease peculiar to them is the effusion of the serum of the blood, and it frequently occurs when the viscera invested by them are the seat of organic disease. The fluid effused into the large serous cavities, frequently contains not merely the components of true serum of the blood, but also fibrin in solution, as is shown by its spontaneous coagulation to a jelly-like mass, which afterwards separates into a clot of small size, and a limpid fluid. In consequence of this coagulation of the fibrin not taking place generally until after the lapse of several hours, it has been, until recently, seldom observed.

The *mucous membranes* line all those passages by which internal parts communicate with the exterior, and by which either matters are eliminated from the body or foreign substances taken into it. They are soft and velvety, and extremely vascular. In their chemical properties they appear to differ essentially from the skin; for they yield no gelatin by boiling, are wholly insoluble in water, and even by long continued boiling are merely rendered hard and brittle. Their basis, or proper texture, would seem therefore to belong to the albuminous structures, (page 115.) Their internal or free surface is covered with epithelium, the structure of which has been described at page 108. The external surface of the mucous membranes is attached to various other tissues: in the tongue, for example, to muscle; on cartilaginous parts, to perichondrium; in the cells of the ethmoid bone, in the frontal and sphenoid sinuses, as well as in the tympanum, to periosteum; in the intestinal canal it is connected with a firm membrane or fascia, (the tunica propria of the intestines,) which on its exterior also gives attachment to the muscular fibres of the third coat of the intestines.

The mucous membranes may be distinguished into several principal tracts:—1. The mucous membrane of the nose, from which prolongations are sent into the sinuses communicating with the nostrils; and which, through the medium of the lachrymal canal and puncta, is continuous with the conjunctiva of the eye and eyelids. The conjunctiva is as certainly a mucous membrane as any other of which the character has not been doubted. It participates in the diseases of the mucous membranes, as well the chronic blennorrhœa as the catarrhal affections; and in every case of violent catarrh of the mucous membrane of the nose, the conjunctiva is affected in both stages of the disease. It has nothing in common with the serous membranes, either in its secretion,—for the limpid secretion of the eyes is derived from the lachrymal gland,—or in its form, which is not that of a closed sac.

2. The mucous membrane of the mouth. This mucous tract communicates in the throat with that of the nose, and sends a prolonga-

tion through the Eustachian tube to line the tympanum, and the inner surface of the membrana tympani. In the mouth, moreover, it sends prolongations into the excretory ducts of the salivary glands; and in the pharynx divides into two great branches, of which the one lines the air tubes, and the other the alimentary canal. The mucous lining of the air tubes ends by forming the delicate membrane of the pulmonary vesicles; while that which is continued into the alimentary canal, besides investing its inner surface in its entire extent, also sends processes into the ducts of the pancreas and liver, and in birds communicates in the cloaca with the next tract of mucous membrane.

3. The mucous membrane of the generative and urinary apparatus, which lines the whole of the urinary passages, from their external orifice to the calyces of the kidneys, extends into the organs of generation as far as the ducts of the glands connected with them, and in the female becomes continuous with the serous membrane of the abdomen at the fimbriæ of the Fallopian tubes.

The mucous membrane of the digestive canal has been already described, (pages 271 and 344.)

In fishes all the mucous membranes are brought into relation with each other through the medium of the mucous surface of their skin.

A remarkable sympathy is observed to exist between all the mucous membranes; thus their diseases, particularly the mucous discharges and the catarrhal affections, have a great tendency to spread in them. By virtue of this sympathy the state of one part of these membranes may be ascertained by examining another part: so that the state of the mucous membrane of the tongue indicates the condition of that of the stomach and intestinal canal. All the mucous membranes have likewise an extraordinary sympathetic connection with the respiratory movements.

The diseases peculiar to these membranes are the blennorrhœæ or mucous discharges, and the catarrhal affections, which are distinguished from the former by their acuteness, that is, the rapidity of their increase and decline, and by their having two stages,—the first, that of congestion,—the second, that of increased secretion.

Mucus is secreted by the lining membranes of the maxillary, frontal, and sphenoidal sinus, and of the tympanum, which have no follicles, as well as by those membranes which have them. The follicles, therefore, cannot be the sole source of the mucous secretion. These follicles or glands, moreover, are merely sac-like depressions of the mucous membrane. In those membranes which are covered with epithelium, by which, therefore, another secretion besides mucus is formed, the latter would seem to be generated in the follicles. All mucous membranes, however, have an investment of epithelium, and the mucus which covers their surface consists chiefly of separated particles of this epithelium mixed with a fluid exudation; while the mucous follicles, where they exist, seem to pour out a fluid holding the mucous globules suspended. The so-named mucous follicles, such as those of the lips and cheeks are, according to Henle, glands of the same structure as the salivary glands. The substance of these glands consists of a mass of round, or oval, completely closed cells of different sizes, and containing some a granular matter, and others perfectly formed mucous globules. A number of these cells united by cellular tissue, and perhaps also by a structureless membrane, form an acinus, and as such are seated upon a branch of the excretory duct, into which the mucous globules and other matter contained in the cells are from time to time poured, in consequence, either of the membrane of the cells bursting, or of its becoming dissolved at the part where it is connected with the duct. But, besides these compound mucous glands, there exist, according to Henle, in almost every mucous membrane, even in those which are supposed to be destitute of glands, other organs, apparently connected with the secreting action of the membrane. These are round or oval closed cells, visible even with the naked eye, and sometimes quite transparent, but at other times filled with mucous globules.*

Mucus is formed by no other than mucous membranes. It is intended as a protection to the surfaces which are exposed to external influences. It swells when placed in water, but is not soluble in it; it does not coagulate by heat; is precipitated from water in which it is diffused, by alcohol; but, after being washed, can be again diffused in the water. The secretion of all the mucous membranes, however, is not exactly the same; for, as Berzelius found, the mucus of the gall-bladder is quite insoluble in acids, while that of the urinary bladder is, to a certain extent, soluble in dilute acids, as well as in dilute alkalies. Ordinarily, acids dissolve a very small proportion of mucus. Gmelin states that the mucus of the intestines is coagulated by acids, even by acetic acid. The acids extract very little of it, and do not dissolve it, even at the boiling temperature. The little that is dissolved by the acids, or that is extracted by digestion in water after the acid is poured off, is precipitated by infusion of galls, but seldom by ferrocyanuret of potassium. The comparison of mucus with pus has been made in a former page (134).

c. The skin.—The proper cutaneous tissue, in which several organs of different kinds are imbedded, consists of fibres interwoven in all directions. The surface of the skin presents little elevations,—papillæ,—which are invested by the rete Malpighii and epidermis. By long-continued (twenty hours) boiling, the skin is reduced wholly, or for the most part, into gelatin. By the property which this substance—gelatin—possesses of forming with tannin a compound which resists putrefaction, is explained the process of tanning.

The skin is the seat of very various secretions, for each of which it is provided with a special organ.

The epidermis is the most general of these secretions. It is formed in layers by the most superficial stratum of the true skin. Most observers agree that the cuticle is not vascular. Schultze has injected with oil of turpentine a very delicate network of vessels which separated with the epidermis from the true skin; but these vessels may have belonged to the sub-epidermic layer, and have been mechanically torn away. Schultze states that they had a diameter several times less than that of the blood globules. If this measurement was not made after the epidermis had been dried, it would afford proof of what is at present a mere hypothesis,—namely, of the existence of vasa serosa.

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* The special secreting organs of the gastric and intestinal mucous membrane have been described in the Section on Digestion.

The hair is secreted in the hair follicles.

The sebaceous matter of the skin is secreted by the innumerable, minute, branched follicles opening by a narrow orific—*folliculi sebacei*—which are distributed over its surface. These sebaceous glands generally open into the follicle of the hairs.*

The perspiration, lastly, is formed by small tubes of peculiar conformation, which are spread over the whole surface of the body, and pour out their secretion by minute pores in the epidermis. These sudoriferous organs were discovered by Purkinje and Breschet.† The pores, which are seen along the elevated lines on the skin of the palm of the hand and sole of the foot, are the opening of minute ducts which traverse in a spiral course the epidermis and stratum Malpighianum, enter deeply into the cutis, and terminate in a gland which is formed of a convoluted tube. In the parts of the skin where the epidermis is thin, the canals themselves are thinner, and more nearly straight in their course. The sudoriferous organs are readily seen by the aid of the miscroscope, in thin perpendicular lamellæ, cut in the direction of the rugæ, from a portion of skin previously hardened in solution of carbonate of potash. The skin of the palm is the best for the purpose.

From this account of the secretions formed in the skin, it results that for each, although it appears only in the form of minute points, a special complicated apparatus is necessary; and that, although the statements of the older anatomists were correct as to the perspiration being poured out by distinct pores, yet the opinion cannot now be admitted that it is directly effused by open branches of blood-vessels; since each perspiratory pore is merely the external orifice of a canal leading to a convoluted tube or follicle, which has no other opening, and, like other glands, forms its secretion on its internal surface.

3. *Glands.*—Of the organs which have hitherto been called glands, some have no ducts leading from them, while others are provided with special efferent tubes to carry off the secretion which they form.

The action of the *first kind* of these organs consists merely in their exerting a certain plastic influence on the fluids which circulate through them. They consist, therefore, almost wholly of vessels; they are *vascular ganglia* ("Gefäss-knoten"); the vessels entering them undergo a most minute division, and then again unite to form the *vasa efferentia*, or vessels which return the fluid to the general circulation.

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* Gurlt, Müller's Archiv. 1835, p. 399. †Gurlt, in Müller's Archiv. 1836, 399.

† See Wendt, de Epidermide Humanâ, Diss. inaug. Vratisl. 1833; and in Müller's Archiv. 1834, p. 280; Breschet, Ann. d. sc. nat., Sept. Oct. Dec. 1834; and Nouv. Recherch. sur la structure de la Peau, par Breschet et Roussel de Vauzème; and Gurlt, loc. cit.

The glands of this kind may be divided into two series:—

a. Those formed essentially of blood-vessels,—*ganglia sanguineo-vasculosa*. Such are the spleen in the chylopoietic system, the supra-renal capsules in the genito-urinary system; the thyroid and thymus bodies in the respiratory system of organs; the glandula choroidalis in the eye of fishes; and, lastly, the placenta of the fœtus.

All these organs are masses of blood-vessels, and seem destined merely to exert an influence on the blood which is distributed in such minute channels through their parenchyma. They are sometimes united into one mass, as the placenta and the spleen; sometimes divided into several, as in the instances of the cotyledons and splenculi of some animals.

b. Lymphatic ganglia,—*ganglia lymphatico-vasculosa*. These are formed of the branches of the inferent and efferent lymphatics, the ultimate divisions of which form a mass of reticulated vessels and cells. Such are the lymphatic and mesenteric glands. Their action, likewise, can only affect the lymph or chyle which traverses them. They, also, are sometimes distinct and many in number, like the mesenteric glands, in most cases; and sometimes united into a mass, as the pancreas Asellii, which consists of conglomerated mesenteric glands.

All these glands, which are glomeruli of blood-vessels or lymphatics, are excluded from consideration in the present inquiry.

Glands of the *second kind* not merely produce a change in the fluid which circulates through them, but also give rise to a new fluid, which is the product of a transformation of the blood, and is poured into special tubes or efferent ducts. The structure of all the glands of this kind must now be examined.

CHAPTER II.

OF THE INTERNAL STRUCTURE OF THE GLANDS.

MALPIGHI, in his *Exercitationes de structurâ viscerum*, published in 1665, laid down the doctrine that the elementary parts of all glands,—the so-named acini,—have the same structure as the simple follicles and the conglomerated follicular glands; that is, that they consist of minute roundish sacs, which receive the secretion from the blood-vessels, and pour it into the efferent ducts. But Ruysch, in 1626, was enabled, by his improved method of making minute injections, to show, without difficulty, that the so-called follicles of the conglomerate glands contain a vast number of minute blood-vessels. Ruysch, however, attributed too much importance to his method of investigation, and to the facts which it enabled him to discover; and he was thereby led to the false conclusion that the proper substance of glands consists solely of blood-vessels, and that the minute blood-vessels terminate by direct inosculation in the ducts of the glands. This doctrine acquired great weight from the circumstance of Haller being inclined in its favour. (*Element. Physiol.* lib. xi. sectio xxiii.) Haller, and several of his followers, have adduced, as arguments for the correctness of Ruysch's view, the escape by the ducts of fluids injected into the blood-vessels of glands, and the occurrence of hemorrhage from secreting tissues. But in all these cases laceration must have taken place. My investigations have shown, also, that, whenever, during injection of the ducts, whether of the liver or kidney, the blood-vessels become filled, the minute ducts themselves have not received any injection; consequently, that extravasation must have taken place. The kidneys appeared to afford the most evident proof of the communication between the arteries and ducts of glands; indeed, long vessels running in the medullary portions of the kidney, and filled with injection-matter thrown into the artery, have been shown at anatomical lectures, to demonstrate the existence and course of the canals or ducts of Bellini. But a more accurate examination by Huschke and myself has discovered that such vessels are not ducts, but blood-vessels.

The investigation of the structure of the kidneys by Ferrein (*Mém. de l'Acad. Roy. de Sc. de Paris*, 1749,) was the first in which an improved method of examination was adopted and instituted with accuracy. Ferrein discovered the convoluted canals of the cortical substance of the kidney, of which neither Malpighi nor Ruysch had suspected the existence, but which Ferrein regarded as the seat of the secretion of the urine. The similarity of these uriniferous canals, discovered by Ferrein, to the *tubuli seminiferi* of the testis, which differ from them merely in being visible to the naked eye, was immediately recognised. The tubuli seminiferi themselves, however, must always be of great importance in the question of the minute structure of glands, since they present to us distinctly an example of the independent existence of the secreting canals, on the parietes of which none but the most minute arteries ramify, and terminate in a capillary network from which the minute veins take their rise.

Mascagni and Cruikshank next showed that the secreting canals in the mammary glands commence in the form of cells; and Prof. E. H. Weber (*Meckel's Archiv.* 1827,) has discovered that the same is the structure of the salivary glands of birds and mammalia, and of the pancreas of birds. The interesting researches of Weber, and the equally excellent observations of Huschke (*Isis*, 1828,) on the structure of the kidneys, were the first step in an inquiry which I have myself since undertaken in its whole extent, having in its prosecution examined the structure of the secreting canals in all kinds of secreting glands. (*J. Müller, de Gland. Struct. Penit. Lips.* 1830.) The result has been the discovery that the secreting canals in all glands form an independent system of tubes; that, whether they be convoluted, as in the kidney and testis, or ramified in an arborescent form, as in the liver and salivary glands,—whether they terminate by twig-like cæca, as in the liver, or in grape-like clusters of cells, as in the salivary glands, pancreas, and mammary gland,—their only connection with the blood-vessels, in all cases, consists in the latter ramifying and forming a capillary network on their walls and in their interstices; and that the finest secreting tubes, namely those of the liver and kidneys, are always several times larger in diameter than the minute ramifications of the arteries and veins.

The individual forms in which the secreting canals are arranged are various; but all secreting glands agree in this, that by the interior of their tubes, or of their convoluted or ramified canals, they afford an extensive surface for secretion, and that the same action is performed by the inner surface of their canals or ducts, as is effected in a more simple manner by a simple secreting membrane. The end, therefore, at which Nature seems to have aimed, in the peculiar distribution of the substance destined to produce a chemical change in the organic matter, is that of obtaining a great surface in a small space; and she has attained this end in the most various ways.

The simplest glands are mere recesses of greater or less size in the surface of a membrane: sometimes they are only very shallow depressions, such as the simple crypts of the mucous membranes; in other instances, they form distinct sacs with a narrow neck, such are the follicles of the mucous membranes, not including the so-called glands of Peyer, of which the structure has been described in the section on digestion; in other cases, again, the membrane is reflected back in the form of a tube, of which we have an example in the mucous canals under the skin of fishes. The *follicle*, "*folliculus*," and the *tube*, "*tubulus*," may indeed be regarded as the elementary forms of the two principal modifications in the structure of glands. But even the follicles, which appear to be the most simple, have a complicated structure; either the interior of the follicle presents cellular dilatations, or the sac is clustered like the Lieberkuehnian crypts of the intestines and the Meibomian glands of the eyelids; or the walls of the follicle are themselves formed of cæcal tubes running perpendicularly to their surface, which is the structure of the gastric glands of birds and other animals.

The various more complicated forms of glands resulting from the further development of the follicle and tube and consequent increase of the secreting surface, may be distinguished as follows:—Several of the sacs or tubes are often closely associated together,—*folliculi aggregati;* sometimes in a linear manner, as the Meibomian glands; in other instances in a mass, like the glandular layer in the *proventriculus* of birds. In this aggregated form the openings of the separate follicles remain distinct; but nature attains the same end by assembling the follicles in one mass opening by a single orifice,—*folliculi compositi, conglomerati;* the tonsils,* the labial and buccal glands, and the prostatic gland of many mammalia, have this structure; the mammary gland of the Ornithorhynchus and the pancreas of the sword-fish and thunny, are likewise instances of a similar form of gland. (*J. Müller, loc. cit. Tab.* 3.) If we imagine the same process of the development of a compound gland to be carried still further, the separate follicles of the composite follicle will send out smaller branches, and a ramified cavity with twig-like or vesicular extremities will result. The compound follicles also may, like the simple follicles, be aggregated together, and then form a larger glandular mass with several or many efferent ducts, of which the human prostate is an example; it consists, namely, of an aggregation of several smaller glands, each of which is formed of a ramified tube with cellular extremities. By the still further progress of the mode of complication here indicated, a compound gland is formed. But only one series of compound glands is developed in this way. A second series consists of those which are constituted of tubes which do not ramify, or only to a very inconsiderable extent: here the increase of surface is obtained by the length and convolution of simple canals which in their entire extent have a nearly equal diameter.

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* On the different forms of the tonsils in the different orders of the mammalia, see a paper by Rapp, in Müller's Archiv. 1839, p. 189.

1. *Compound glands with canals of the ramified type.*—The principal glands comprehended under this head are the lachrymal, mammary, and salivary glands, the pancreas, and the liver. They are divisible into two groups: *a.* glands in which the ducts ramify with a certain degree of regularity, the principal trunk giving off branches laterally at certain intervals, and these sending out in the same way side branches, which in their turn afford a third set; this is the mode of ramification in the lobulated glands, the lachrymal, mammary, and salivary glands, and the pancreas; and hence it is that these glands have orders of lobules loosely connected by cellular membrane, which correspond to the degrees of division of the ducts. The smallest parts of such glands visible with the naked eye are in some instances granules, or acini, which are only aggregates of cells seated in clusters on the extremities of the most minute secreting canals, and surrounded by a network of capillaries; the cells themselves being too minute to be visible except in their distended state and with the aid of the microscope.* In other instances, the minute secreting canals are arranged in the form of extremely delicate cæca around the branches of the duct, like the leaves of mosses on their stem; this form of ramification is seen in the liver of the higher crustacea, and in the lachrymal gland of tortoises and turtles, and likewise gives rise to the formation of lobules. In other glands again, for instance in the Cowper's glands of the hedgehog, (*J. Müller, loc. cit. Tab.* iii. *fig.* 8, 9,) the radicle ducts of a minute lobule terminate, as in the last-described forms, without becoming vesicular, but are arranged in tufts of twig-like tubes.

b. The second group of glands with ramified secreting tubes, consists of those in which the ramification is irregular, and in which there is no division and subdivision of the glands into lobules. The liver belongs to this group; the tufts of the most minute branches of the biliary ducts form acini, it is true; but these acini are united into one lobe, or several common lobes, without being previously collected into lobules.

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* The recent observations of Henle and others on the structure of these cells and of the tubular secreting canals of other glands will be found at the end of the present Chapter.

This irregular mode of ramification, and the circumstance that the final branches of the ducts terminate not in cells, but, after manifold division, in twigs of microscopic minuteness, a great number of which are united to form what is called an acinus, characterise the liver of vertebrate animals. The liver of the Invertebrata frequently belongs to the first group.

[*] We will now describe the structure of the principal glands of this class,—the glands with ramified secreting tubes,—which are met with in the human subject.

A. *The lachrymal gland.*—In *birds* and *Mammalia* the secreting canals of the lachrymal glands are regularly branched, and terminate in each acinus in a number of little cells. These cells are very large in birds; and in them, as well as in the horse, can be filled with mercury from the efferent duct.

B. *Mammary gland.*—The varieties of conformation of this gland may be referred to *two general types.* It is either composed of cæca, or of branched ducts which ultimately terminate in bunches of microscopic cells. The mammary gland opens on the surface of the nipple in some *Mammalia*, as the ruminants, by a single orifice; in others, as man and the carnivora, by several; in the latter instances, there are, in fact, several glands in each mamma. The structure of these glands may be very beautifully shown by filling the ducts even to the terminal cellules with mercury. The diameter of the cellulæ lactiferæ is from ten to thirty-five times greater than that of the smallest capillary vessels in the human body.

C. *Salivary glands.*—In *Mammalia*, the form in which a salivary gland first appears is, according to Weber's and my own observations, that of a simple canal with bud-like processes, lying in a gelatinous nidus or "blastema," and communicating with the cavity of the mouth. As the development of the gland advances, the canal becomes more and more ramified, increasing at the expense of the germinal mass or "blastema" in which it is still enclosed. The blastema soon acquires a lobulated form corresponding to that of the future gland, and is at last wholly absorbed. Thus, in the first stage of their development, the salivary ducts can be seen to constitute an independent, closed system of tubes; but in the adult state also, the vesicles which terminate the ultimate microscopic branches of the ducts, can be filled with mercury from the excretory duct. Professor E. H. Weber has succeeded in doing this in the human subject, and I have effected it in the dog. The most minute cells which, when filled with mercury, have a diameter about three times greater than that of the capillary blood-vessels, are united into small grape-like bunches or lobules from four to seven times larger than the cells themselves. The most minute pulmonary air cells are from five to sixteen times larger than the cells of the parotid gland.

D. *Pancreas.*—The mammary gland is, in its simplest form, namely, in the Cetacea, composed merely of cæca; and the pancreas likewise appears first in the same form, constituting the pyloric appendices of *fishes.* These pancreatic or pyloric cæca, which indeed are wholly wanting in some fishes, vary in their number and complexity. The process of development of the pancreas, as it is observed in *the tadpole*, is similar to that of the salivary glands in mammalia. But even in the adult state *in birds* E. H. Weber and I have succeeded in injecting it with mercury, so as to fill the cell-like extremities of its secreting canals. The diameter of these cells is from six to twelve times greater than that of the capillary blood-vessels.

E. *The liver of Mammalia* is a very difficult subject of investigation, and it is only from its mode of development that we can derive any certain conclusions as to its intimate structure. It is an extremely difficult matter to make a good injection of the minute biliary canals, while the blood-vessels may be injected in their whole extent.

Development of the liver, and its structure in birds and Mammalia. The observations of Rolando, Baer, and myself have placed it beyond a doubt that the liver in the embryo of the bird is originally developed by the protrusion, as it were, of a part of the walls of the intestinal canal, which is likewise the mode of development of the lungs and pancreas. According to Baer, (in *Burdach's Physiologie*, Bd. ii.

p. 504,) the liver of the embryo of the bird is first visible about the middle of the third day, in the form of two conical hollow branches of the alimentary tube, which embrace the common venous stem. The cones increase in length, pushing before them ramifications of blood-vessels, while their base becomes gradually narrowed, and assumes the form of a cylindrical duct. Whilst the liver is being thus developed by the protrusion of the parietes of the intestine in the form of two hollow cones into the vascular layer that invests it externally, internal ramifications are developed in the cavities of the cones, and these at the same time become united at their base, in consequence of more and more of the surrounding part of the intestinal parietes being taken up to form them, till at last the part that separated them is removed to a distance from the intestine; and the cavities, originally double, open by one mouth into the intestinal tube. The gall-bladder is developed as a diverticulum from the hepatic duct.

Respecting the latter stages of the formation and ramification of the biliary canals, we have some observations of Harvey and Malpighi. Harvey (*Exercit. de generat. animal.* 19,) described the substance of the liver as growing like sprouts or buds from the external surface of the blood-vessels; on the sixth, seventh, and ninth days the liver appeared to Malpighi (*De format. pulli*, 61,) to consist of cæca. I have, with the aid of the microscope, followed still further the progress of its development. On the surface of the liver in the embryo I have seen innumerable cæca, or short twig-like bodies, of a yellowish white colour, projecting from the blood-red substance, in which they lay very closely aggregated together. In more advanced embryos the cæca appeared more branched, so as to have the form of feathers, or even of arborescent tufts. Each of the cæca measured about $\frac{1}{333}$ of an English inch in diameter.

It required patient microscopic examination of the injected liver to recognise the most minute branches of the ducts, and they lay so closely together that they appeared to be united one with another: their diameter varied from $\frac{1}{833}$ to $\frac{1}{750}$ of an English inch; they were larger therefore than the capillary blood-vessels. It is remarkable that the minute biliary canals of the embryo, unlike the minute canals of the salivary glands, terminate, as we have seen, by blind twig-like extremities, and that no bud-like or vesicular enlargements appear on them at a later period of their development.

Several writers, Autenrieth, Bichât, Cloquet, Mappes, and Meckel, have spoken of two substances as existing in all parts of the liver, and as constituting a cortical and medullary portion of each acinus. From my researches, however, it results, that there is but one kind of real hepatic substance, formed of agglomerated biliary canals; but the ramified divisions of this substance being connected by a vascular cellular tissue, which is often of a dark colour, a contrast between this and the yellow substance of the acini is produced. A similar relation of the constituent parts of the liver exists in the embryo of the bird,—in it the yellowish twig-like ramifications of the biliary canals are seen, on the surface of the organ, rising out of a reddish vascular tissue.

Distribution of the blood-vessels in the liver.—Injection thrown either into the hepatic artery or into the portal vein fills the same capillary network from which, on the other hand, the hepatic veins likewise arise. It appears, therefore, that the arterial blood of the hepatic artery and the venous blood of the porta become mixed in the minute vessels of the liver, and that the secretion of bile probably takes place from both. The most delicate capillaries are, as I have said, more minute than the microscopic cæca of the biliary ducts. They form a network which occupies all the interstices of the secreting canals, and invests them, but has no direct communication with them; for in the embryo of the bird, and in the larva of the frog also, the secreting canals of the liver can be seen with the aid of the microscope to terminate on the surface of the organ with blind extremities. In the larva of the salamander, the blood can with the microscope be seen circulating between the acini of the liver.

The very valuable researches of Mr. Kiernan (*Philosoph. Transact.* 1833, pt. 2, p. 711,) have advanced our knowledge of the anatomy of the liver. He describes the lobules of the liver (which by other anatomists are termed acini) as leaf-shaped, but not flattened, bodies, which send out several short rounded processes. In the interior of each lobule runs a central vein, (*venula intralobularis*,) which is a branch of the hepatic vein, and which returns the blood from the capillary network of the lobule. The branches of the hepatic vein from which these intralobular veins arise, run in canals formed by the bases of the lobules, and on their inner surface appear perforated by foramina which are the mouths of the venulæ intralobulares issuing from the bases of the lobules. All the lobules of the liver, therefore, contribute by their bases to form canals for the hepatic veins. The external surface of each lobule is invested by a sheath of cellular membrane,—a prolongation of the capsule of Glisson,—and in this cellular membrane, which at the same time separates the lobules one from another, the branches of the hepatic artery and those of the portal vein run. The latter veins (the *venæ interlobulares*) terminate in the capillary network of the lobule, from which the intralobular veins on the other hand arise. Congestion of either of these systems of veins gives rise to a difference of tint in the corresponding part of each lobule, of which the natural colour is yellowish: if the portal or interlobular veins are congested, the centre of the lobule appears pale; if the congestion affects the hepatic or intralobular veins, it is the margin of the lobule which is left of the paler yellow colour; and hence has arisen the erroneous supposition that the lobules are composed of two substances.

The cellular tissue of the capsule of Glisson is continued from the transverse fissure into the interior of the liver, forming a common sheath for the hepatic artery, portal vein, and hepatic duct; it surrounds all the branches of the porta and the accompanying branches of the artery and duct, and terminates at last in the interlobular cellular tissue. The branches of the hepatic vein are in no way connected with these cellular sheaths.

The hepatic artery is, according to Kiernan, distributed principally to the walls of the gall-bladder, the bile-ducts, and the other blood-vessels, to which it supplies the vasa vasorum. From the capillary network that results from its ramification, he supposes the blood to pass into branches of the portal vein, and thence into the hepatic veins; for, when fine injection was thrown into the hepatic artery, the portal veins became filled, but not the hepatic veins. Having injected the porta first with blue, and the artery afterwards with red, he found branches of both vessels in the coats of the vessels of the bile-ducts and of the gall-bladder; the lobules of the liver were coloured blue, and merely points of the red injection were seen here and there in their marginal portion. These are Kiernan's grounds for believing that those branches of the hepatic artery which enter the lobules do not terminate directly in the hepatic veins, but pour their blood first into branches of the porta, from which it is afterwards transmitted to the hepatic veins. The commonly received opinion, that all the blood of the liver—that of the hepatic artery as well as that of the portal vein—is poured into the same capillary system, would, according to Kiernan's view, be incorrect; but his opinion is not yet satisfactorily confirmed, and it is opposed to what we can observe in the injected preparations of Lieberkühn, in which the injected matter is seen to have frequently passed into the same network as readily from the one as from the other vessel.*

2. *Glands with a tubular structure.*—The kidneys and testicles are examples of this structure in the human body. The increase of secreting surface is here obtained by means of convoluted canals of great length, which do not ramify, or only in a slight degree, and maintain the same diameter in the greater part of their course.

In *the embryo of Mammalia and of the human subject* the kidney consists of several distinct lobes (renculi) which are connected only by the divisions of the pelvis of the kidney. The renculi correspond in number to the pyramidal or medullary portions of the kidney of the adult animal. In several animals,—the bear, the otter, and the cetacea—the renculi remain separate throughout life. Each renculus in the animals just mentioned, as well as in the fœtus of mammalia and of man, consists of the pyramidal medullary portion, with a layer of cortical substance investing its base like a cap, and continued at its sides even as far as the mammella. The entire cortical substance consists of convoluted ducts, of which the diameter remains the same in their whole length. In the horse's kidney the cortical substance is thin, and the convoluted tubes are therefore less numerous. It is very difficult to find the extremity of the convoluted urinary tubules. Weber examined the human kidney with the microscope, but could find no ducts terminating with free ends; all seemed to form loops. By the aid of the air-pump I have succeeded in injecting the horse's kidney from the ureter, and have discovered that in it the *tubuli uriniferi* anastomose freely. The weight of evidence in favour of the tubuli uriniferi, in man and Mammalia generally, terminating wholly by anastomosis, is therefore now, by Mr. Owen's observations, rendered great.

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* With reference to this question, Prof. Müller has recently remarked in another place (Müller's Archiv. 1838, p. cxiii.), that if the portal vein were tied, the matter injected into it through the hepatic artery, would necessarily pass at length into the hepatic vein also; and Lieberkühn's preparations, he adds, may have been made in that manner.

The *disposition of the blood-vessels in the substance of the kidney* is extremely interesting. In the cortical structure they form the ordinary capillary network, of which the meshes are so close that the intervals are not many times larger than the diameter of the capillaries that enclose them. Among the tubuli uriniferi of the cortical substance lie the acini of Malpighi, bodies larger than the urinary canals, and visible even with the naked eye. Schumlansky has drawn them much too small. They lie in vesicular cavities of the cellular tissue between the tubuli uriniferi, and consist wholly of convoluted blood-vessels. It is remarkable that they exist in the kidneys of most, perhaps of all, vertebrate animals; they have been found in the kidney of the frog, toad, salamander, turtle, and tortoise, birds, mammalia, and man, and recently by Hyrtl in the kidney of fishes. They can be filled with injection from the arteries as easily as from the veins, and are simply receptacles for blood, and not as Schumlansky supposed the beginning of the tubuli uriniferi.

The convoluted tubuli uriniferi themselves are the seat of the secretion of urine, which is poured out by their whole internal surface, not by their extremities only. They are everywhere surrounded by minute currents of blood, circulating in the capillary network which fills their interstices, and is extended over their external surface. The fluid part of the blood may permeate the delicate parietes of the uriniferous canals, and suffer in its transit a chemical change, or the effete matters contained in the blood of the capillaries may be attracted and separated from it by the agency of those canals.

In the medullary portions of the kidney no blood-vessels run between the urinary canals in straight lines, from the cortical portion towards the mammella. These straight blood-vessels are easily injected either from the arteries or the veins, and were formerly supposed to be urinary canals, and to prove the existence of a communication between the blood-vessels and ducts of glands. But they differ from the secreting canals in becoming smaller as they approach the mammella, on which they terminate in the common capillary network which surrounds the openings of the tubuli uriniferi.

The secreting canals of the kidneys are extremely similar to the tubuli seminiferi; both are convoluted and form anastomoses, but the canals of the kidneys are the more minute; in the human subject they are several times smaller than the seminal tubes, therefore cannot be seen with the naked eye. In serpents, and in the sharks and rays, on the contrary, they are so large as to be visible without the aid of a glass.

The structure of the *human testis* has been recently investigated by Sir A. Cooper, (on the *Structure of the Testis*, translated into German. Weimar, 1832,) and with still greater success by Prof. A. Lauth, (*Mém. de la Société de l'Histoire Natur. de Strasbourg*, liv. ii.) and by Krause, (*Müller's Archiv.* 1837, 20.) Sir A. Cooper describes the lobules of the testis as being not merely separated from each other by processes of the tunica albuginea which form septa between them, but as being each enclosed in an exceedingly delicate membrane. The *tubuli seminiferi* taken together are all directed towards the rete testis, and may be regarded as forming one cone of which the apex is towards that part; each tubulus, likewise, is so disposed, that, by the convolutions into which it is reflected becoming smaller and smaller as it approaches the rete, it forms a cone, the apex of which is directed to the same point. The diameter of all the tubuli is the same. The measurements are given in the table at the end of the chapter. A lobule contains, according to Lauth, sometimes one, sometimes two, at other times several tubuli. He reckons the number of the tubuli at 840, and the length of one at two feet three inches. Krause found from 404 to 484 lobuli in a single testis. I had observed some of the seminal tubes terminating by free extremities in mammiferous animals: the observation is most easily made in rodentia on account of the larger size of the tubuli in them. Lauth has but once seen a seminal canal ending with a free extremity in the human testis. Krause has seen such free ends of the tubuli seminiferi frequently, and confirms the opinion of their terminating in that way as well as by anastomosis. Lauth attributes the circumstance of free extremities of the tubes being so seldom seen to their uniting with each other so as to form loops. He describes the division and re-union of the tubes to be so frequent that, in a small portion which he spread out, and in which there were about forty-nine inches of tube, he found about fifteen anastomoses. It is, however, only towards their extremity that the seminal tubes anastomose thus freely. The discovery of the anastomoses of the seminal tubes is perfectly original.

The tubuli seminiferi form a system of closed tubes of the same diameter throughout, hence we cannot suppose that the semen is secreted merely by their extremities; on the contrary, their whole internal surface must perform that office; and, since they are fifteen times thicker than the smallest branches of the arteries which ramify on their coats, a direct inosculation between the two systems of vessels cannot be thought of.

When the tubuli seminiferi have reached to within a line or two of the rete testis, they cease to be convoluted; several unite together, and then enter the rete under the name of the tubuli recti, of which there are, according to Lauth, certainly more than twenty, the number ascribed to them by Haller. Their diameter is greater than that of the tubuli seminiferi. The rete testis occupies a great portion of the upper border of the organ; it commences a short distance from the internal extremity, and extends as far as the external third of the upper border, varying in length from six to eleven lines; it is contained in the thickness of the tunica albuginea, and gives rise to an internal white process of that tunic, called the corpus Highmori, the height of which measures from two to four lines, the base from three to five lines. The rete testis consists of from seven to thirteen vessels, which run in a waving course, anastomose with each other, and again divide, being all connected together. The vasa efferentia, which issue from the rete, and go to form the head of the epididymis, are at first straight, but soon become convoluted, each forming a cone of which the apex corresponds to the rete testis, the base to the head of the epididymis. Lauth says that the efferent canals diminish in size as they approach the epididymis; their number is from nine to thirty, their length eight inches. They enter the canal of the epididymis one after another, the interval between the entrance of every two being, according to Lauth, three inches three lines. The average length of the canal which forms the epididymis is stated by Lauth to be twenty-one feet.

The vasculum aberrans is usually found at the angle which the vas deferens makes when it applied itself to the epididymis; it generally unites with the termination of the canal of the epididymis, less frequently with the commencement of the vas deferens. In rare cases there are several vasa aberrantia. The vas aberrans is a cæcal appendage of a yellowish colour; its length, when unravelled, varies from one and a half to fourteen inches. The part nearest to the epididymis is always smaller than the rest of the canal, and much smaller than the tube of which the epididymis is formed. Towards its cæcal extremity it becomes gradually larger; and sometimes, after being dilated for a certain extent, terminates by becoming again extremely minute. Its office is evidently the secretion of a fluid which it pours into the epididymis. Whether it bears any relation to the corpora Wolffiana of the embryo is not known.

The *general results relative to the structure of the glands,* which may be deduced from the foregoing anatomical description of the individual secreting organs, are the following:—

1. However various the form of their elementary parts, all secret-

ing glands without exception (not only those of the human body, but all met with in the animal kingdom) follow the same law of conformation, and constitute an uninterrupted series from the simplest follicle to the most complex gland.

2. No line of demarcation can be drawn between the secreting organs of invertebrata and those of vertebrate animals; not merely do we meet with the simplest sacs and tubular secreting organs, like those of insects, in the higher animals, but there is a gradual transition from the simple secreting organs of insects to the glands of the most perfect vertebrata. The mammary glands of the Ornithorhynchus, the simplest salivary glands of birds, the prostate gland of many Mammalia, the pancreas of most fishes, are as simple as the secreting organs of the Crustacea.

3. All glands agree in affording by their interior a large surface for secretion. The varieties of internal surface by which the great end,—extent of surface in a small space,—is attained, are very numerous. Nature displays here, as elsewhere, an infinite profusion in the variation of forms, without departing from the simplest laws of development. An extraordinary variety of form is presented, with almost a vegetable character, by the seminiferous tubes in insects; and still more extraordinary is the variety in the form of the secreting canals which attends the increasing complication of the more perfect glands in the higher animals; but all glands have the common character of being an efflorescence, as it were, from the principal efferent duct in the form of cavities or canals with closed extremities. Malpighi's theory of the structure of glands is therefore certainly correct, its truth has been placed beyond doubt by recent researches; but Malpighi was not acquainted with the true glandular elements; the parts in the compound glands which he called follicles, are not really the elementary parts, but are themselves formed of much more minute elements agglomerated together around the branches of the efferent ducts. Moreover, the blind extremities of the secreting tubes are not always follicles; they may be long cæca; or ramifying cæcal canals united in a pinnate form; sometimes they are bunches of cells, in other instances large convoluted tubes which preserve their diameter throughout, and anastomose frequently with each other. The main point in Malpighi's doctrine, however, is correct; namely, that all the terminal branches of the ducts are closed cavities. The lungs may serve as the type of an entire series of glandular organs.

4. *Acini*, in the hypothetical sense in which the term has been used by writers,—in the sense, namely, of secreting granules,—do not really exist; there are no glomeruli of blood-vessels with ducts arising from them in a mysterious way, as has been supposed, whatever notions may have been held regarding them.

5. The parts described as *acini* are merely masses formed by the agglomeration of the extremities of the secreting canals; frequently, indeed, they are formed of minute vesicles, aggregated together in grape-like bunches, which may be injected with mercury, and are often susceptible of inflation. The only example of glands really consisting of solid granules is afforded by the testes of some few fishes.

6. In many glands which have been incorrectly described to have acini or secreting granules, even the hollow vesicular terminations of the ducts do not exist: the secreting tubes, instead of terminating in vesicles or cells, form long convoluted canals of the same diameter throughout, as in the kidney and testes, and many other glands; or straight tubuli, as in the lachrymal gland of the testudo mydas; or short cæca, as in the liver of Crustacea and the prostatic gland of many Mammalia. In certain glands of a grape-like structure, such as the salivary glands, the pancreas, the mammary gland of most Mammalia, the lachrymal gland of birds and Mammalia, the Harderian gland, the liver of mollusca, &c., there are certainly vesicular terminations of the secreting canals constituting a "substantia acinosa." The expressions "*substantia acinosa*," "*acini*," and similar terms, are applicable consequently to such glands, inasmuch as "acinus," according to its derivation, means a small grape. But this meaning has been gradually corrupted, through the succession of hypotheses, to that of a secreting granule, granular substance; and, since the term "acinus" is strictly applicable only in the case of a few glands, it is advisable to be very cautious in the use of a word with which so many false explanations and hypotheses are connected.

7. It has been demonstrated in the case of all glands that the blood-vessels are not continuous with the secreting tubes—that the minute vessels bear the same relation to the coats of the hollow secreting canals and their closed extremities, as to any other delicate secreting membrane, such as, for example, the mucous membrane of the pulmonary air cells. The arteries do not open by free mouths into the radicle extremities of the secreting canals and cavities of the glands; but terminate by numerous anastomoses with the veins, forming a network which is distributed over the surface of the elementary parts of the gland.

8. Thus the blood-vessels, like the secreting canals, constitute an independent closed system of vessels; the arteries and veins, after ramifying in an arborescent manner, being connected together by a net-work of closed tubes.

9. It was formerly asserted that in some glands a communication exists between the ducts and the lymphatics. Such is not the case; my reasons for denying it have been already stated.

10. The system of secreting canals with closed hollow extremities is to be regarded as an efflorescence of the efferent ducts, and may indeed be observed to be developed in the embryo from an originally undivided tube.

11. The arborescent ramifications of the blood-vessels accompany the ducts in their development, and the reticulated capillaries in which the blood-vessels terminate are extended over all the closed elementary parts of the gland and supply them with blood. In the chick we may observe the simultaneous development of the two systems; in proportion as the development of internal surface from a plane membrane to cæcum and ramified cæca proceeds, the vascular layer of the originally simple membrane is raised on the exterior of the efflorescence.

12. The ramified canals and tubes, which, when the structure is simple, as in insects and Crustacea, and even in some glands of the Mammalia, lie freely and unconnectedly, become more aggregated together, and acquire a common covering, in proportion as their evolution is carried further, and thus is produced a parenchyma, or solid organ. This process of development has been made the subject of direct observation in the embryo.

13. The capillary blood-vessels are for the most part much more minute than the smallest branches of the ducts or secreting canals, and their cæcal extremities, even in the most complex glandular organs. The elementary parts of glands, though minute, are of such a size that the capillary blood-vessels form around them a network which invests them. See the foregoing anatomical description of the different glands, and the table of microscopic measurements at the end of the present chapter. During the development of all the compound glands, while the secreting canals are still free, and not aggregated together, the same relation as to size can be seen to exist between them and the capillary blood-vessels.

14. The formation of the glands in the embryo displays the same progressive evolution from the simple to the complex state, as is observed in ascending the animal scale. The most perfect and complex glands of the higher animals, when they first appear in the embryo of these animals, consist merely of the free efferent ducts without any branches, and in that state exactly resemble the secreting organs of the lower animals; the glands are formed from the unbranched tubes by a kind of efflorescence or ramification.

15. The mode in which the extent of internal secreting surface of a gland is realised is very various; and no one kind of conformation is peculiar to any one gland. Perfectly different glands may have a similar elementary structure, as is the case, for instance, with the testes and the cortical structure of the kidneys. And similar glands have often a perfectly different structure in different animals; of which the lachrymal glands, examined in the chelonian reptiles, birds, and Mammalia, afford an example. How various, too, is the elementary structure of the liver in the animal series; in one case being represented by simple cæca; in another, by tufts of cæca; in others again, by bunches of cells, or by a spongy mass; or, lastly, by branched ducts ending in feather-like terminal twigs! How infinitely various is the conformation of the secreting tubes of the testes! The kidneys alone maintain one constant character in all classes of animals; namely, that of consisting of long tubes which do not ramify, but run either parallel with each other or interwoven, although the arrangement of these tubes is subject to the greatest variation.

16. We do not observe an absolutely progressive development of the glands from the lowest to the most perfect animals; on the contrary, we meet in every class with rudimentary glands of extremely simple structure, constituting their first form in the class: thus, the salivary glands have this simple structure in birds and serpents; and the mammary gland of the ornithorhynchus, the prostate gland of

rodentia, the pancreas of fishes, and the liver of the lower animals, consist merely of cæca.

17. However different the secretions of the glands may be, the substance of their elementary parts is in all instances white, or of a greyish or yellowish white colour. There is no essential correspondence between the substance of the gland and the matter which it secretes.

Hitherto the attention of anatomists has been directed only to the the various forms in which Nature has arranged the substance of glands, apparently for the purpose of gaining extent of secreting surface, while the microscopic characters of the glandular substance itself has seemed of little interest. The recent observations of Purkinje, Schwann, and Henle, however, have pointed out a new subject for investigation in the elementary particles which constitute a great part of the secreting organs, and form the walls of the secreting cavities. Purkinje remarked that the parietes of secreting cavities generally, as well of the follicles of the stomach as of the secreting canals of the various glands, are formed of nucleated granules, composing what he denominates the glandular *enchyma*. In this enchyma he places the special secreting power of the glands, attributes to each of the granules a *vita propia*, and compares them to the cells of plants, which prepare their special contents from the general fluids. Schwann makes similar observations, and, like Purkinje, regards the columnar cells of the epithelium of mucous membranes generally as the secreting organs of those surfaces. The nucleated epithelium cells of the secreting canals of the kidney and testis, of the lachrymal, mammary, and salivary glands, and the analogous parts in the liver and sebaceous follicles, have been most accurately described by Henle. The secreting tubuli of the kidney are invested internally with a layer of flattened cells, with distinct nuclei. The diameter of each nucleus is about 0.0033 of a line. In the cortical part of the kidney the tubuli appear, as Henle describes them, to be wholly composed of a layer of these cells; but in the medullary portion there is distinctly visible an external, delicate, membranous tube of homogeneous structure, which sometimes appears destitute of epithelium. The vesicular extremities of the secreting canals in the mammary, salivary, and lachrymal glands, and in the pancreas, contain similar epithelium cells. M. Henle has recently stated that the terminal vesicles of these glands are, like those of the mucous follicles, closed cells, within which the secretion is formed, and which from time to time open and pour their contents into the ducts of the glands. It is certainly difficult, in microscopic examination, to trace distinctly a communication between the cavity of these vesicles and that of the ducts; but it appears to the translator equally difficult to prove that such communication does not exist; he has never seen the vesicles separate from the mass as perfectly closed cells, and the facility with which they are injected from the ducts is rather opposed to M. Henle's description. The observations of Wasmann respecting the cellular structure of the follicles of the stomach has been noticed in the chapter on the Structure of the Digestive Organs.

The acini of the liver are accurately described by M. Henle as composed in greater part of polygonal cells, containing each a pale oval or round nucleus, and several globules of fatty matter of different sizes. The nucleus is, as M. Henle states, most distinct in those cells which contain no fat globules. In the cells composing the acini in the sheep's liver, the translator perceived, as they rolled over in the fluid, that the oil globules were attached to the inner surface of the wall of the cell. These globules of fatty matter are doubtless what M. Turpin described as young vesicles developed within the component vesicles of the liver: for the young cellules in the acini of the liver are really developed from nuclei in the interstices or on the exterior of the old cells. It is difficult to determine the relation which the cells of the liver bear to the terminal branches of the hepatic duct. Purkinje says that they form the lining of the ultimate twigs of the ducts, but nothing like the secreting canals of the other glands can be distinguished by mere microscopic examination in the substance of the acini or lobules of the liver. The whole cavity of the secreting vesicles of the Meibomian glands is, according to Henle, filled with cells like those of the liver; and the contents of the sebaceous glands of the skin were found by him to consist of similar cells.

Table of measurements of different microscopic parts.

	In fractions of an English inch.
Capillaries (according to Professor E. H. Weber)	$\frac{1}{3760}$ to $\frac{1}{1800}$
Do. in the kidneys (according to my measurement)	$\frac{1}{2490}$ to $\frac{1}{1590}$
Do. in the human iris	$\frac{1}{2490}$ to $\frac{1}{1964}$
Do. in the ciliary processes	$\frac{1}{1740}$
The smallest *pulmonary air-cells* in the human subject (according to Weber)	$\frac{1}{100}$ to $\frac{1}{60}$
Cylindrical cæca in the lung of the embryo of the bird	$\frac{1}{102}$
The *elementary vesicles* of the *mammary gland* in the hedge-hog giving suck	$\frac{1}{120}$ to $\frac{1}{90}$
Do. Do. in the dog, filled with mercury	$\frac{1}{352}$
Cells of the salivary glands in the goose, injected by myself	$\frac{1}{352}$
Do. Do. the parotid, in the new-born infant, injected by Weber	$\frac{1}{1122}$
Do. Do. Do. in the dog, injected by myself	$\frac{1}{403}$
Cells of the *lachrymal gland* of the goose, measured from my injections	$\frac{1}{510}$
Elementary parts of the lachrymal gland of the testudo mydas	$\frac{1}{472}$
Cells of the *Harderian gland* of the hare, from my injections	$\frac{1}{112}$
Do. Do. of the goose, filled with mercury,	$\frac{1}{3}$ $\frac{1}{4}$ $\frac{1}{5}$ of a line.
Cells of the *pancreas* of the goose, filled with mercury	$\frac{1}{673}$ to $\frac{1}{356}$
Elementary vesicles of the *liver* of the helix pomatia	$\frac{1}{163}$
Elementary tubes of the liver of the embryo of the jay, one inch in length	$\frac{1}{224}$
Terminal twigs of the biliary ducts on the surface of the liver of the embryo of the rabbit, injected	$\frac{1}{264}$ to $\frac{1}{791}$
Cæca of the *Wolffian bodies* of the embryo of a bird	$\frac{1}{224}$
Do. Do. of another embryo	$\frac{1}{307}$
Tubuli uriniferi of the petromyzon marinus	$\frac{1}{284}$
" " of the electric ray	$\frac{1}{102}$
" " of serpents, filled with mercury	$\frac{1}{383}$
" " Do. their extremities	$\frac{1}{213}$
" " of the owl, injected from the ureter, their extremities	$\frac{1}{243}$
" " of the cortical substance of the kidney of the squirrel	$\frac{1}{519}$
" " on the surface of the horse's kidney, injected from the ureter	$\frac{1}{673}$ to $\frac{1}{483}$

	In fractions of an English inch.
Tubuli uriniferi in the pyramidal portions of the horse's kidney at the mammellæ, the largest	$\frac{1}{48}$
" " Do. those of the medium size	$\frac{1}{133}$
" " Do. the smallest seen in sections of the cortical substance	$\frac{1}{525}$ to $\frac{1}{262}$
" " in the cortical substance of the human kidney (Weber)	$\frac{1}{512}$
" " in the pyramidal portions	$\frac{1}{319}$
" " measured on the mammellæ	$\frac{1}{553}$
The *glomeruli or corpora Malpighiana* of the human kidney	$\frac{1}{191}$
The same (Weber)	$\frac{1}{151}$ to $\frac{1}{168}$
The straight arteries in the pyramidal portions of the dog's kidney	$\frac{1}{1285}$ to $\frac{1}{248}$
The same near the mammella, where they form a network	$\frac{1}{2197}$
Tubuli seminiferi of a young cock	$\frac{1}{172}$
" " of a squirrel	$\frac{1}{83}$
" " of the hedge-hog	$\frac{1}{95}$
" " of the human testis	$\frac{1}{185}$
" " " " filled with mercury	$\frac{1}{87}$
The tubuli seminiferi of the human testis, according to Lauth	$\frac{1}{176}$
" " " " filled with mercury	$\frac{1}{148}$
The tubuli recti (Lauth)	$\frac{1}{95}$
The canals of the rete testis (Lauth)	$\frac{1}{165}$ to $\frac{1}{138}$
The tubes in the *anal glands* of the goose	$\frac{1}{96}$
The twig-like cæca or tubes of *Cowper's glands* in the hedge-hog	$\frac{1}{96}$
Cells of the human *Meibomian glands* (Weber)	$\frac{1}{356}$ to $\frac{1}{125}$

Cells in the salivary glands of the murex tritonis, $\frac{1}{8}$ to $\frac{1}{3}$ of a line.

Cells of the spongy liver of the murex tritonis, $\frac{1}{6}$ to $\frac{1}{4}$ of a line.

Compare the measurements of different parts given by Krause in Müller's Archiv. 837, p. 20.

CHAPTER III.

OF THE PROCESS OF SECRETION.

1. *Of the causes of secretion.*

Secretion is merely one kind of those changes or "metamorphoses" which the circulating fluid of animals—the blood—undergoes in its course. In all the organs of the body the blood passes through a network of very delicate vessels,—the capillaries,—which constitute the medium of communication between the arteries and the veins. The capillaries have no open mouths, but their parietes are extremely thin and delicate, and do not prevent a free interchange of material between the substance of the organ and the currents of blood. The substance of the organ imbibes the blood and appropriates to itself the components of that fluid, assimilating them in a different way in each individual organ.

General conditions of a secreting organ.—All secretions are formed on free surfaces, whether these be afforded by simple membranes, such as the serous and mucous membranes, or by the more complex internal surface of the cellular or tubular cavities of glands. In the secreting membranes the blood is transmitted from the arteries to the veins through an infinite number of anastomosing vessels which form an extended network. The membrane is permeated by the liquid portion of the circulating fluid, effects in it some change, and pours out the matter thus changed as a secretion on its surface.

The most complex gland, with its ducts, canals, tubuli, cells, or cæca, is to be regarded in like manner as merely a very extensive organised surface on which the transformation of the blood takes place.

The elementary tubular canals of the kidney, and the elementary parts of the liver, as well as of the other compound glands, are in their whole course surrounded with a network of capillaries, and are separated from each other merely by delicate cellular tissue, which connects them together, and contains in its substance the minute currents of blood. The whole external surface, therefore, of the elementary canals, racemes of cells, tubuli, &c. is overrun with small currents of blood; and the walls of the canals, &c. being permeated by the fluid portion of the blood, impress on it some peculiar change, and pour out the fluid in its altered state on their inner surface, to be carried out by the efferent duct. This is the simple process of secretion, which differs from nutrition merely in the circumstance that the part of the blood which has undergone the peculiar change is eliminated on a free surface instead of being added to the substance of the organ.

Seat of the secreting process.—It was formerly supposed, in opposition to all analogy, that the secreting process had its seat in the extremities of the glandular canals, or in those mysterious bodies, the acini. But that was a very incorrect view, as Professor E. H. Weber has already remarked; for the acini, which, in the proper anatomical sense of the word, are hollow vesicles, exist in but few of the compound glands; and it would be anything but reasonable to say that the secretion was formed solely at the closed extremities of the branched ducts and tubular canals of other glands, such as the liver and kidneys. Some compound glands, moreover, present in the course of the excretory duct the same elementary parts as at the extremities of its branches, whether they be cells, as in the salivary and lachrymal glands of birds and the Meibomian glands of the human subject, or cæca, as in the liver of crustacea and the lachrymal gland of the chelonia. When glands consist of aggregated cæca, the limit between the elementary parts of the gland and the efferent duct cannot indeed be at all indicated. It is therefore extremely probable, or rather certain, that the process of secretion goes on throughout the whole extent of the glandular canals, consequently from one continuous surface.

Mode of exhalation.—The older physiologists were led to imagine the existence of exhalent vessels through their ignorance of that property of animal tissues by virtue of which all matters in solution are imbibed and transmitted from one part to another, through invisible pores. But it is now known that the exhalent vessels do not exist, and that, in a secreting surface, the blood-vessels simply form a very close network. The depth at which this network lies, in a membrane not covered with epidermis, has been already shown to be exceedingly slight. The fluid parts of the blood circulating in the capillaries will, therefore, readily permeate the particles of the special tissue of the secreting membrane, and may escape on its free surface, after having undergone a chemical change by its influence. We do not hereby explain the power by which the secretion is thrown off from the secreting surface, but merely the possibility of the fluid finding its way through the coats of the vessels and the membrane. Many secretions are attended with a profuse exudation of fluid, which, like many other phenomena, cannot for a moment be attributed to the force of the heart's action, and the impulse thus communicated to the blood: such a mechanical explanation is by no means satisfactory; for besides the absence of the heart's action to account for secretion in plants, the cases in which secretion is increased by local irritation, the heart remaining unaffected, are quite inexplicable by such means. Another difficulty to be solved is the cause of the escape of the secreted fluid solely on the free surface of the membrane:—Why does not the mucus, for example, collect as readily between the coats of the intestine as exude from the inner surface? Why does not the bile permeate the walls of the biliary ducts, and escape on the surface of the liver as readily as it forces its way outwards in the course of the ducts? Why does the semen collect on the inner surface only of the tubuli seminiferi, and not in their exterior—in their interstices? The elimination of the secreted fluid on one side only of the secreting membrane, namely, on the interior of the canals, is one of the greatest enigmas in physiology; it may perhaps be explained by either of the following hypotheses:—

1. It may be imagined that the capillaries of the gland are provided with exhalent pores so constructed as to allow fluids to pass through in one direction only, namely, towards the cavity of the glandular canals. But here the difficulty occurs, that this hypothesis presupposes the existence of what cannot be demonstrated, and that we must again suppose that there are other pores in the coats of the capillaries for the passage of the fluids destined for the nutrition of the secreting canals.

2. The more probable supposition is, that by virtue of imbibition, or the general inorganic porosity, the fluid portion of the blood becomes diffused through the tissue of the secreting organ; that the external surface of the glandular canals exerts a chemical attraction on the elements of the fluid, infusing into them at the same time a tendency to unite into new combinations, and then repels them, in a manner which is certainly quite inexplicable, towards the inner surface of the secreting membrane or glandular canals.* That the process which we are endeavouring to explain, does not consist merely in exudation, but is dependent on an action of the secreting membranes, is evident from the quantity of the fluid poured out by a

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* Compare the observations of Mascagni on this subject:—"Nova per poros inorganicos secretionum theoria vasorumque lymphaticorum historia iterum vulgata et parte alterâ aucta, in quâ vasorum minimorum vindicatio et secretionum per poros inorganicos refutatio continetur." Auct. P. Lupi. Romæ, 1793.

stimulated salivary gland, and from the suddenness and abundance of the secretion of tears excited sometimes by momentary impressions.

Although quite unsupported by facts, this theory of attraction and repulsion is not without its analogy in physical phenomena; and it would appear that very similar powers effect the elimination of the fluid in secretion, and cause it to be taken up into the lymphatics in absorption. It is an extraordinary circumstance that frequently, in different component tissues of the same membrane, both processes are going on within a very small space; that in the mucous membranes, for example, the mucous follicles, which secrete, are closely surrounded by the lymphatics, which attract and absorb.

Dr. Wollaston supposed that secretion was attended with electrical action. He relates the following experiment:—A glass tube two inches in length, and $\frac{3}{4}$ of an inch wide, was closed at one end with bladder, and partly filled with water containing $\frac{1}{240}$ of common salt. The bladder was moistened on the exterior and placed on a plate of silver; a zinc wire being now connected by the one end with the plate of silver, and by the other brought in contact with the water, pure soda appeared on the outer surface of the bladder. Eberle, (*Physiologie der Verdauung*, p. 137,) however, found a stronger galvanic influence necessary to produce this effect.

The cause of the peculiarity, and difference of secretions can be found in no external mechanical conditions. They have been attributed to difference in the rapidity of the blood's motion in the different organs; but it should first be proved that the rapidity of the blood's motion does differ in this way. They have been ascribed, again, to different states of the blood-vessels, and to the particular angles at which they divide; but it may be seen in Lieberkühn's preparations that the blood-vessels in the kidneys divide nearly in the same way as in the testes, and in the salivary glands not far otherwise than in the liver; and in all parts reticulated capillaries are seen forming anastomoses between the arteries and veins. Others, again, have endeavoured to account for the differences of secretions by differences in the free ends of the arteries, but we have shown that arteries have no free extremities with open mouths. Others attribute a great influence to the different diameters of the canals which receive the secretions, and yet the most various and peculiar fluids are secreted on simple membranes. All these circumstances, on which Haller has laid far too much stress, even if they existed, would not be sufficient to explain the difficulty. Besides, how easily may all such mechanical explanations be dismissed by this simple question:—What gives rise to the formation of brain on the one hand, of muscle on the other, and, again, in another case of bone? Does the brain also depend for its formation on a peculiar angle of division of the blood-vessels?

The peculiarity of secretions does not depend on the internal conformation of the glands; for, as I have sufficiently demonstrated, each secretion is in different animals the product of the most various glandular structures, and very different fluids are secreted by glands of similar organisation. The nature of the secretion depends therefore solely on the peculiar vital properties of the organic substance which forms the secreting canals, and which may remain the same however different the conformation of the secreting cavities may be; while it may vary extremely although the form of the canals or ducts remains unchanged. The variety of secretions is due to the same cause as the variety of the formation and vital properties of organs generally; the only difference being that, in nutrition, the part of the blood which has undergone the peculiar change is incorporated with the organ itself, while in secretion it is eliminated from it.

Several chemists, and especially Chevreul, have recently laboured to prove that all secretions are formed independently of any change effected by the organ in the components of the blood; that all the materials of the different secretions pre-exist in the blood itself; and that the principal action of the secreting organ is merely to attract these matters from the blood and to transfer them to the fluid secreted. As circumstances favouring this view very strongly, Gmelin mentions, that the salts of the blood and those of the secretions are nearly identical; that, both in the blood and in the secretions, osmazome, and a substance resembling salivary matter, occur; and that many of the substances which were formerly believed to exist only in the secretions, namely, casein, cholesterine, stearine, elain, and elaic acid, have been discovered in the blood. The existence of cholesterine in the blood has been recently confirmed anew by Boudet. (*Essai critique et expérimental sur le Sang.* Paris, 1833.)(*a*) Nevertheless the theory appears to me to be founded on a very erroneous view; for, in the first place, neither horn, mucus, biliary matter, picromel, semen, true casein, true salivary matter, nor the poisonous matters secreted by animals, are contained in the blood; and secondly, components of the secretions may accidentally re-enter the blood by imbibition, so that their presence in it is no proof of their being part of its natural constituents; and, in fine, the existence of all the secreted matters in the blood would not do away with the difficulty, for it would remain to explain how they were formed in it,—for instance, in the blood of herbivorous animals. It is, indeed, quite certain that the "true secretions," as distinguished from the "excretions," are, like the solid parts of the body, formed from the more simple constituents of the blood by the organs which secrete them.

The *chemical process of secretion* is not at all understood. The simple problem to be solved is, how the secreting membranes can, at the same time, and from the same blood, nourish themselves,—that is, attract analogous particles and add them to their own substance,—and also secrete or eliminate non-analogous particles; for the secreted fluid is in its chemical properties wholly different from the secreting organ. The glandular substance, generally, consists merely of uncoagulated albumen, which, when reduced to a state of minute division, is readily soluble in water. The elementary parts

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(*a*) See on this subject Liebig's *Animal or Organic* Chemistry.

of a secreting organ are, as far as I have observed, of a grey, greyish-white, or yellowish-white colour; thus, even in the liver of the embryo, the biliary canals seen on the surface of the organ are of a yellow-white colour, and it is only owing to the reticulated capillaries that the liver has a brown aspect; yet the bile is green. In oviparous animals the urine is white, but the substance of the kidneys has a totally different appearance, as may be observed in very young birds just escaped from the shell, where the minute urinary canals are visible on the surface of the kidneys, filled with the white urine, as if injected. Berzelius did not detect in the substance of the kidney, the peculiar chemical constituents of the urine. (*Berzelius*, *Chimie Animale*, translated by Jourdan, p. 333.) The substance of the liver is, it is true, found to contain fatty matters which are components likewise of the bile, and in disease it is prone to become converted into fat; but the essential constituents of the bile have not been detected in it. Braconnot's analysis of the liver shows that its composition is very different from that of the bile; and Kuehn (*Kastner's Archiv.* xiii. p. 337,) has obtained from the liver a fatty matter which differs by very marked characters from cholesterine. Besides, it must be remembered that it is almost impossible to obtain any of the substance of the organ entirely free from bile. But restricting ourselves to the "secreting membranes," we find that the skin, for example, contains no horny matter, and yet it secretes that substance; and the tissue of the choroid, when washed, seems itself to contain no *pigmentum nigrum.*

It is therefore certain that the matter secreted differs in its chemical properties from the organ which forms it, and that secretion cannot be a mere liquefaction of the substance of the organ; that, on the contrary, the substance of the secreting surface, while it attracts to itself analogous matters from the blood for the purpose of nutrition, at the same time separates from it something that is non-analogous.

In the nutrition of organs which afford no secretion, those components of the blood which are analogous to the tissue are attracted by it, while the non-analogous components re-enter the circulation; but in the process of secretion non-analogous matters are thrown off and carried out of the body.

It might then be imagined, that each molecule of blood which comes under the decomposing influence of a secreting organ, is completely decomposed and disposed of by it; so that those of its elements which go to the nutrition of the organ, and those which form the secretion, would, reunited, produce blood. If the molecule of blood is expressed by the sign a, and a molecule of the component matter of the secreting organ by x, the secretion would, according to the above supposition, be $a-x$. We have no data to determine whether this hypothesis is correct or not; therefore, I will not adopt it, but mention it merely as an idea worthy of consideration in further researches. It is a simple and therefore attractive hypothesis, but is at once seen to be untenable in the case of those secretions in which the matters separated from the blood have—as urea, for example,—been formed in other parts of the body.

That the secretion undergoes a further change,—that its formation is perfected,—in its passage through the narrow and often very long canals of the glands, may be conceived to be possible, but is not susceptible of proof. There has always been a disposition to admit this supposition in the case of the testis; but since the tubuli of the kidney are as long as those of the testis, while the urine is a mere excretion and does not require any further elaboration, it is evident that the length of the tubes has a more important relation to the extent of the secreting surface than to the production of any further change in the fluid already secreted.

The *chemical composition of the individual secretions* offers at present little interest in relation to the general physiology of secretion, and is important only in connection with the several functions in which they are implicated; the "secreta" therefore are treated of in the sections devoted to those functions. Those which are met with more generally throughout the body,—fat, mucus, and synovia,—have been described with the secreting-membranes; the bile, saliva, the gastric and pancreatic secretions, have also come under consideration in the section on digestion; the urine and perspiration will follow under the head of the excretions; semen, milk, &c. with the subject of generation.

The *microscopic globules found in some secretions*, as the semen and milk, for instance, are important. I have observed in the bile of the frog very scanty granules, unequal in form and size, the largest about five times smaller than the red particles of the animal's blood; the green colouring matter of the bile, however, is in solution; Weber also describes granules as existing in the bile. I have likewise found granules in very small number in the saliva; Weber finds them to be larger than the red particles of the blood, and transparent: the greater part, however, of the solid matter of the saliva is in solution. Weber could discover no globules in the perfectly transparent portion of mucus; he saw only the ordinary flakes of the mucus. It appears to me, that by far the largest proportion of the components of the saliva, bile, and mucus, as well as of the urine, is in solution; while in the semen, milk, pigmentum nigrum, and pus, on the contrary, there are granules in such number that they must be looked upon as among the most essential ingredients of these fluids. The granules of the pigmentum nigrum are, according to Weber, of unequal size, but in the mean about $\frac{1}{7388}$ of an English inch; they are therefore about half as large as the red particles of the blood. The globules of the milk are described by Weber as being very transparent, and round, but irregular in size; in the mean $\frac{1}{3}$ or $\frac{1}{2}$ smaller than the blood particles. Treviranus remarks, that they do not sink in the fluid, and that they refract the light strongly, and hence he infers that they are globules of fat. Weber regards them as composed of casein and fatty matter. The pus globules are, according to Weber, round, and measure from $\frac{1}{2770}$ to $\frac{1}{1383}$ of an inch in diameter, the size of the majority being $\frac{1}{2213}$ of an inch; they are therefore about twice as large as the red particles of the blood. All the foregoing facts prove that the globules of the secreted fluids are not red particles of the blood which have undergone a change; the globules of the milk are too small, those of the pus too large; the latter cannot come from the interior of the capillary vessels, for their diameter is greater than that of the smallest of these vessels. Besides, if red particles thus altered could find their way out of the vessels, others in the unchanged state would escape with them. The view which I take of the mode of production of the globules of the milk, pigmentum nigrum, and pus, is, that they are either thrown off from the substance of the secreting surface, or formed by the partial coagulation of the animal matter dissolved in the secretion into globules, (in a way similar to the coagulation of albumen from its solution,) which is probably the mode in which the particles of the milk and pigmentum nigrum are produced. With respect to the origin of the globules of pus, Autenrieth (*Physiol.* ii. 119,) relates the following remarkable observation:—If some of the watery moisture which exudes from the surface of an inflamed part after the pus has been removed, is collected between two transparent thin plates of talc, and allowed to lie in the wound, globules are seen to form gradually in it, to enlarge and become opaque; while, if the fluid is removed altogether from the atmosphere of the living textures, no such change takes place in it. Brugmans* also states, that if a suppurating surface has been washed clean, the pus is seen to be secreted as a clear fluid, which afterwards becomes thick and opaque.† See also the observations of Vogel relative to the formation of the pus globules.

2. *Of the influence of the nerves on secretion.*

There is at present little known concerning the influence of the nerves on the process of secretion. The experiment instituted by the Baron A. Von Humboldt on his own person, is well known. Having applied two blisters to the region of the shoulders, he covered one of the blistered surfaces with a silver plate, and closed the circle by means of a conductor of zinc, when a painful burning was produced, and a change in the character of the discharge; from being bland and colourless, it became a red acrid fluid, which left livid red streaks on the parts of the back where it ran. (*Ueber die gereizte Muskel und Nerven-faser*, i. 324.) M. Most (*Ueber die grossen Heilkräfte des Galvanismus*, 1823) likewise states, that, having caused a galvanic current to pass through the parotid, by applying the positive pole to the situation of the gland for the space of ten minutes while he held the negative pole in his hand, an increased secretion of saliva, which was neither acid nor alkaline, took place.

The influence of the nerves on secretion has as yet been made the subject of few direct experiments; but it is certain that, after division of the nervus vagus, the secretion of gastric juice generally ceases.‡

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* Diss. de Pyogenia, 114.—Schroeder van der Kolk, Observ. Anat. Pathol. 21.

† On the subject of this section, consult Wedemeyer, über den Kreislauf des Blutes; Doellinger, Was ist Absonderung? Würzburg, 1819.

‡ Tiedemann und Gmelin, die Verdauung, i. 340. The French translation by Jourdan, pt. i. p. 372.

That this is not always the case, however, is proved both by the experiments performed on geese by myself, in conjunction with Dr. Dieckhof, and by those of Dr. Reid on dogs. (See the remarks on the influence of the nerves on digestion in a preceding Section). Brodie (*Phil. Trans.* 1814, p. 104,) has shown, by a series of experiments, that, when the nervus vagus and nervus sympatheticus* have been divided, arsenic does not give rise to the copious secretion in the stomach and intestines which usually follows its exhibition. Dr. Reid (*Edin. Med. and Surg. Journal,* vol. 51, p. 322,) has repeated these experiments of Sir B. Brodie, but with a different result. The watery secretion and mucus were formed in the stomach and intestines in as great, or nearly as great, abundance in dogs of which the nervi vagi had been divided, as in other dogs in which the operation had not been performed. The secretion of the pulmonary mucous membrane also is altered by division of the vagus; hence the frothy blood exudation which is found in the lungs after that operation. Dr. Reid, however, has rendered it probable that the effusions into the bronchi are not a direct effect of the section of the nervi vagi, (see page 327).

Krimer has instituted some experiments relative to the influence of the nervous system on the secretion of urine, an influence which is proved to exist by the circumstance that nervous affections are usually attended with secretion of limpid urine containing an unnaturally small proportion of its proper ingredients. Krimer† states, that on examining the state of the urinary secretion after having divided the nerves of the kidneys, he has found it contain albumen and red colouring matter of the blood, their proportion increasing in the same degree as that of the proper constituents of the urine decreased. Division of the vagus did not put a stop to the secretion of urine; but rhubarb and prussiate of potash taken by the mouth ceased to pass off by the urine, which at the same time acquired greater specific gravity from containing serum of the blood: when the divided nerves, however, were connected with the galvanic pile, the urine reacquired its normal character, and was found to contain the above-mentioned substances. After division of the spinal cord in the dorsal or lumbar region, the urine became limpid like water; while division of the sympathetic nerve in the neck caused it to become alkaline and albuminous; its normal properties being, however, restored on the application of galvanism. Brachet‡ has made similar observations on the effects of interrupting the transmission of nervous influence to the kidney. He divided the renal artery of a dog, and then connected its two portions by means of a canula, so that the renal nerves were divided, but the supply of blood maintained. The fluid, which flowed from the ureter during several hours succeeding the operation, was red, and separated into a fibrous coagulum and serum. Repetition of the experiment was attended with the same result. Division of the nervi vagi had no effect on the secretion of urine.

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* This is an erroneous statement. Sir B. Brodie's experiments had reference to the effects of division of the vagus only, and not of the sympathetic nerve.

† Physiol. Untersuchungen. His experiments are given in Lund's Physiolog. Resultat. der Vivisect. neuerer Zeit. Kopenhagen, 1825, p. 204.

‡ Recherches Experiment. sur les fonctions du Syst. Nerv. Ganglion. Paris, 1830, p. 269.

I have recently, in conjunction with Dr. Peipers, instituted a series of experiments on dogs and sheep, to determine the influence of the nerves in secretion. We applied a ligature to the renal vessels (the ureter being excluded), and tied it so tightly that the texture of the renal nerves included in it should at that point be destroyed. We then loosened the ligature again, so that the circulation of the blood through the kidney was re-established. The ureter was brought to the exterior of the body and a tube connected with it. In most cases the secretion of urine was completely arrested, even when the same operation was performed on the second kidney (in a sheep), and the ligature retained on that side to render the secretion of urine there quite impossible. Once only, namely, in a sheep, the secretion continued in the injured kidney; but the fluid was bloody, and M. Wittstock found that it contained hippuric acid. The softened state of the substance of the kidney after the performance of these experiments, which were often repeated, was very remarkable. (*Peipers, de Nervorum in Secretion. Actione, Berol.* 1834).

The influence of the nerves on the glands may be of a different nature in each gland, or, which is more probable, it may be the same in all, merely enabling the secreting substance, in each gland endowed with peculiar properties, to exert its chemical action. Daily experience affords us many proofs of the influence of the nerves on secretion. We know that, during the depression of the nervous system in the cold stage of fever, not only the quantity of all the secretions, but also the proportion of their natural ingredients is diminished; and that, with the accession of the hot stage, the secretions are restored. We also know that dryness of the mucous membranes and of the skin are often signs of depressed nervous influence in acute diseases. How frequently, too, do we observe the influence of passions of the mind on secretion, for example, on the secretion of the tears, of the bile, and the milk, and even on the secretion and other conditions of wounds. It has indeed been stated that the presence of the foal has an effect on the secretion of milk in the mare. I will not lay stress on the accounts of the poisonous action of the saliva of enraged animals; for the phenomena observed in such cases to follow the bite are generally, perhaps, merely those dependent on the form of the wound: but it is a well-known and undoubted fact, that not merely the presence of food in the mouth causes an increased flow of saliva, but that even the sight of savoury food excites the salivary secretion. If it were possible wholly to cut off the nervous influence of a secreting organ, we should find perhaps, as after division of the nervus vagus in reference to the gastric juice, that the function of the special secretions is wholly arrested by the interruption of nervous energy. I am far from believing that the power of chemical action, which the glandular substance owes to its vital condition, has not as equally important a share as the nervous influence in the process of secretion; but it is probable that the influence of the nerves is necessary for the support of this chemical action, which in each gland is different.

On a first view, the cerebro-spinal, as well as the sympathetic nerves, appear to have the function of regulating secretion. The distribution of the lingual nerve in the submaxillary and sublingual glands, of the glosso-pharyngeal nerve in the tonsils, and of a branch of a tibial nerve in the capsule of the knee-joints, are well-known anatomical facts. It is remarkable, that the female mammary gland receives its nerves, not directly from the sympathetic, but, as it appears to me, only from the third and fourth intercostal nerves. It is extremely probable, however, that the cerebro-spinal nerves are accompanied by fibres of the sympathetic; indeed, Retzius has shown this to be the case with the second branch of the fifth nerve in brutes, and in them it is evident also in the case of the nervus buccinatorius, on the surface of which may be traced many grey nerves, derived from the otic ganglion. In hemiplegia from disease of the brain or spinal marrow, the secretion of the surface on the affected side, in some cases, is altered, in others remains unchanged.

3. *Of the changes of which secretions are susceptible.*

The process of secretion may be disturbed from local, as well as from general causes.

The state of the secreting organ affects not merely the quantity, but even the quality of the secretion: the urine is watery, and contains less of its proximate components, after nervous attacks: the mucus secreted in the different stages of a catarrh is very different, —at first it is watery and salt, afterwards more consistent; but the inflammation at length generally arrests entirely the special secretion of every secreting organ, as it does the function of other organs. Stimulants or irritation affect secreting organs in a peculiar manner; at first the secretion is increased in quantity, but, in proportion as the irritation passes into inflammation, the state of increased action diminishes. When secreting organs become relaxed, and their texture loose, the secretion is generally increased in quantity, but diminished in consistence,—it becomes more watery; when they are relaxed, and at the same time their texture thickened, the secretion is lessened in quantity. This observation applies to all secreting organs, the mucus membranes of the nostrils, the conjunctiva, and the skin. Morbid secretions are subject to the same law: an ulcer when stimulated, affords a copious secretion of pus; if it becomes highly inflamed, the secretion is stopped; if the ulcer is relaxed,—its walls loose and flabby,—it secretes a copious watery fluid; while if, at the same time that its action is feeble, its tissue is thickened by the deposition of the products of inflammation, the secretion formed by it is very scanty.

Interruption of nervous influence causes diminution of the quantity of the natural secretion of a secreting organ; thus, in hysterical paroxysms the urine is almost colourless; in fevers, with depressed state of the nervous energy, and in the cold stage of all fevers, the skin is dry. But it is extraordinary, that a much more complete arrest of the nervous energy,—such as occurs in syncope, and under the influence of terror,—may cause an unusually copious secretion on the skin, producing cold sweat, or in the intestines, giving rise to diarrhœa. We are acquainted with the changes produced in the composition of secretions, in consequence of affections of the nervous system, rather by their injurious effects,—for instance, by the effects of milk and bile secreted after the mind has been the subject of violent emotions,—than by any chemical examination to which they have been submitted.

Since all secretions, inasmuch as they extract certain ingredients from the blood, produce a change in its composition, no one secretion can be altered in quantity or quality without disturbing the balance which exists between all in their action on the blood; hence, the increase of one secretion gives rise to the diminution of another. On the principle of this relation between the different secretions, or their "antagonism," as it is called, depends the practice of exciting artificial discharges to put a stop to morbid secretions. The antagonism of the secretions is observed to be subject to the following laws:

1. The increase of a secretion in a tissue, A, which is less irritable than the organ, B, is incapable of producing a diminution in the secretion of the latter; hence, for example, secretions from the skin, artificially excited, as by a blister, in the neighbourhood of the eye, are of no service, in inflammations of the latter organ, because the eye is a more irritable part than the skin.(*a*)

2. An increased secretion in a certain tissue, A, cannot be diminished by exciting the same secretion in another part of the same tissue, A; on the contrary, such a procedure would rather increase the secretion from all parts of the tissue than diminish it, because the relation which exists between the different parts of the one and the same tissue is that of sympathy, not of antagonism. Hence, a discharge from the generative or urinary organs cannot be arrested by an artificially excited diarrhœa.

3. On the contrary, the secretions of tissues which do not belong to the same class of structures, often antagonise each other. Thus, increase of the cutaneous secretion frequently induces diminution of the secretion of the kidneys; in summer the cutaneous exhalation is more abundant, and the urinary secretion proportionally scanty; and in winter the reverse is the case. Effusion of watery fluids into the cellular membrane and serous cavities is attended with dryness of the skin and diminution of the urinary secretion, the quantity of which is observed to increase in the same proportion as the dropsical effusions diminish. Suppression of the exhalation from the skin by cold, gives rise to mucous discharges from the intestinal and pulmonary mucous membranes.

4. It is only towards the termination of consumptive diseases that this relation of antagonism between the secretions ceases to exist, when in consequence of the relaxed state of the tissues, all are at length increased in quantity; in the colliquative state that precedes

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(*a*) The premises must be faulty here, for the practical inference is erroneous.

death in phthisical patients, colliquative diarrhœa, profuse sweating, and dropsical effusions take place simultaneously.

5. When one tissue is excited to increased action by an impression made upon another, either the secretion of the two must have been in some respects similar, as in the case of the skin and kidneys, both of which have the office of excreting water from the blood; or the organ thus excited must have had a predisposition to morbid action, which is the rational explanation of the circumstance, that the impression of cold produces in one person an affection of the mucous membrane of the lungs, in another, a disordered secretion of mucus in the intestinal canal.*

Sometimes the suppression of a secretion in one part of the body gives rise to the appearance of the same fluid in another part. This happens most frequently with those matters which exist in the blood previously to the act of excretion. Effusions of blood, vicarious of the menstrual flux, have certainly occurred; and the total destruction of both kidneys, by preventing the elimination of the urea already present in the blood by the ordinary channel, must tend to induce effusions of fluids impregnated with urea in all the other parts of the body. Nysten† has ascertained the existence of urea in fluids formed in other parts during the total suppression of the renal secretion; and it is an undoubted fact that lithate of soda is contained in the depositions of gout.

If, however, the essential ingredient of the secretion does not exist in the blood itself, the suppression of this secretion in the organ destined to form it, cannot cause its metastatic appearance in other parts; the instances which have been adduced of such an occurrence are ill-supported by proofs.

In the cases in which the total suppression of one secretion gives rise, by an antagonistic influence, to the production of another, the ingredients of which cannot be derived ready formed from the blood, the new secretion is always essentially different from that, for the suppression of which it seems to compensate, and resembles it only so far as is compatible with its natural proximate elements. True vicarious secretion of milk, for example, never occurs. Autenrieth has remarked that such supposed secretions of milk from other organs do not contain the essential components of milk, namely, the sugar of milk and butter. They contain only those proximate components of the blood which might have served for the formation of milk, such, for example, as albumen. We have already shown the fallacy of the views relative to the supposed metastatic secretion of pus. (See pages 264–5.)

The glandular secreting canals pour out the product of their chemical action on their interior surface. (See the remarks on this law at the beginning of this Chapter.) It is only in very rare cases—as in the form of jaundice excited by affections of the mind,—that the newly-formed matter seems to be again carried into the circulation.

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* Consult Heusinger, über den Antagonismus der Excretionen, in his Zeitschrift für organ. Physik. Bd. i.

† Recherches de Chim. et de Physiol. Pathol. Paris, 1811, p. 263–293.

4. *Of the discharge of the secretions.*

The *efferent ducts* of glands are lined by a mucous membrane, which has on its exterior an extremely thin layer of muscular substance. The existence of muscular fibres cannot, it is true, be demonstrated anatomically,* but physiological observations place it beyond dispute; the efferent ducts of most glands have the power of contracting when irritated. The contractile power of the ductus choledochus in birds was known to Rudolphi. By irritating mechanically or by galvanism the ductus choledochus of a bird just dead, I have frequently produced a very strong contraction of it, which continued some minutes, after which the duct resumed its previous state. I have often excited strong local contractions of the ureters likewise, both in birds and in rabbits, by the application of a powerful galganic stimulus. Tiedemann† also has seen motions of the vas deferens of a horse ensue on the application of a stimulus. It appears, indeed, that periodic vermicular motions are performed by the efferent ducts, at least by the ductus choledochus in birds; for once, namely, in a bird just killed, I observed contractions of the duct to occur regularly in pauses of several minutes; the tube dilating again in the intervals. It was here remarkable, that the contractions took place in an ascending direction, namely, from the intestine towards the liver; which seems to throw some light on the mode in which the bile at certain times, instead of being expelled into the intestines, is retained and driven into the diverticulum of the duct,—the gall-bladder; the complete closure of the mouth of the duct contributing perhaps to this effect.

The discharge of the bile from the gall-bladder during digestion results probably from the mere pressure of the surrounding parts, and the action of the abdominal muscles, while the mouth of the duct is open: for I doubt if the gall-bladder is contractile; I could produce no contraction of it in Mammalia and birds, even with the most powerful stimulus of a galvanic battery; and in this respect it differs from the other diverticula of efferent ducts, namely, the urinary bladder, and the vesicula seminalis, which it resembles in all other characters.

Dr. G. H. Meyer, (*Op. citat.*) however, states, that by means of a galvanic battery of fifty pairs of plates, he has caused the gall-bladder of an ox to contract so as to diminish its capacity one-fourth.

The nature of the internal coat of the efferent ducts, and the contractility of their middle coat, prove most clearly that they are merely diverticula of the membranous tubes into which they lead; thus, the ductus choledochus and pancreaticus, consisting as they do of the same membranes as the duodenum, are prolongations of its coats.

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* This appears to have been done, however, by Dr. G. H. Meyer, (Diss. inaug. de Musculis in duct. eff. glandul. (Berol. 1837.) He describes the course which the fibres take in the different layers of the muscular coat of the ureters of the horse and gall-bladder of the ox.

† Ueber die Wege, auf welchen Substanzen aus dem Magen und Darm-kanal ins Blut gelangen, p. 22.—Recherches sur l'Absorption; traduit par Heller. Paris, 1821.

How far the contractility of the ducts may contribute to the frequently sudden expulsion of the saliva and tears, is a question which I mention merely as requiring further investigation. I may, in conclusion, remark, that since the contractility of the ducts of glands is proved experimentally, the spasm of these parts, spoken of by physicians, ceases to be a mere hypothesis.

CHAPTER IV.

OF THE ELIMINATION OF THE EFFETE DECOMPOSED MATTERS.

Life is attended with a constant decomposition of organic matter; the causes of this we have already investigated (Prolegomena). We have seen that the action of external stimuli is necessary for the continued manifestation of life; that their action produces a change in the composition of the organic matter of the body; and that, while more important organic compounds are generated, the useless ingredients of the substances which suffered decomposition are excreted. We know, moreover, that even the conversion of the new nutriment into blood is necessarily attended with the excretion of useless elements. The apparatus by which these effete matters are eliminated, not formed, are the skin and kidneys. The nature of the excretions, however, is the subject of our present consideration. The organic conditions on which secretion and excretion generally depend have been treated of in the section on Secretion.

Relative quantity of the excretions.—Dr. Dalton (*Edinb. New Philosoph. Journ.* 1832, 1833,) has made a number of experiments in his own person, to determine the proportion which exists between the quantity of the aliment and that of the excretions in a healthy subject. In the first series, instituted in the month of March, and continued during fourteen days, 91 ounces, or nearly 6 pounds, was the mean quantity of solid and fluid aliment taken into the system daily. The average amount of urine excreted each day was 48½ ounces, of fæces 5 ounces, making together 53½ ounces; so that, provided the weight of the body remained the same, the amount of matter exhaled daily by the skin and lungs must have been 37½ ounces. The second series of experiments was instituted in summer, in the month of June; the daily amount of solid excreta was then less by 4 ounces; while the quantity of the urine was greater by 3 ounces, the quantity of matter carried off by exhalation was 44½ ounces,—6 ounces more, consequently, than in the spring. In autumn half the daily amount of food was got rid of by exhalation. Dr. Dalton calculated that the aliment which he took in twenty-four hours, contained about 11½ ounces of carbon. Now he estimates the proportion of carbon in the urine at 1¼ per cent.; it would, therefore, in 48½ ounces amount to $\frac{5}{10}$ or $\frac{6}{10}$ of an ounce. A hundred parts of fæces contain 75 parts water, and of the remainder not more than 10 parts are carbon. In 5 ounces of fæces, consequently, there would be but half an ounce of carbon, and 10½ ounces of this element must be got rid of by cutaneous and pulmonary transpiration. By earlier experiments (*Manchester Memoirs*. New Series. Vol. ii. p. 27,) Dr. Dalton had ascertained that the amount of carbon exhaled from his lungs in twenty-four hours averaged about 10¼ ounces. The average quantity of water expired was at most 20½ ounces. So that in twenty-four hours 30¾ ounces of effete matters—water and carbon—are excreted from the lungs, leaving 6¾ ounces to be exhaled by the skin, of which 6½ ounces would be water and a quarter of an ounce carbon. According to this calculation, then, the quantity of the matters exhaled by the lungs is five times greater than that of the cutaneous transpiration. Dr. Dalton estimates that of the six pounds of new matter taken daily as nutriment, one pound consists of carbon and nitrogen, the rest being for the most part water.

Excretion of foreign matters.—Foreign matters, which have been taken up into the circulation, are not excreted at the same time and with equal facility by all the free surfaces of the body. On the contrary, it is observed that the different excreting organs manifest different degrees of attraction for different foreign substances, of which some are excreted more readily by one organ, others by other organs. Thus, it has been shown by Magendie, (*Bulletin de la Société Philom.* 1811,) and Tiedemann, (*Zeitschrift für Physiol.* S. 2,) that alcohol, camphor, spirit of turpentine, musk, sulphuret of carbon, and phosphorus, are exhaled by the lungs; while saline and many colouring matters pass off, either changed, or in their original state, more especially by the kidneys. It may be stated generally, that those matters which are prone to pass out of the system by a certain secreting organ, are likely to be stimulants of that organ, and hence we may explain the stimulant action of the neutral salts on the kidneys, these salts being generally excreted in an unchanged state with the urine. The results of Woehler's researches (*Ibid.* Bd. i.) on the excretion of foreign matters by the kidneys will be detailed in the article on the urine.

1. *Cutaneous Exhalation and Perspiration.*

The skin is the seat of a twofold secretion,—a fatty matter, and a vapour. The properties and composition of the first, which is formed by the sebaceous follicles of the skin, have not hitherto been examined. In the fœtus it forms an unctuous coating to the surface of the body, and consists then, according to Frommherz and Gugert, of an intimate mixture of a fat similar to cholesterine and albumen; the latter, however, may be derived from the liquor amnii.

The sources of the watery exhalation are the skin and the lungs. During strong exercise and exposure to great external warmth, in some diseases, and also when evaporation is prevented by the application of oiled silk or plaister, the perspiration collects on the skin in the form of drops of fluid—the sweat. The sweat is secreted by the minute spiral follicles, or sudoriferous canals, discovered by Purkinje and Breschet, which are distributed over the whole surface of the skin.

Quantity of the cutaneous transpiration.—Since the laborious researches of Sanctorius, who instituted ingenious experiments for the purpose of ascertaining the quantity of the matters lost by exhalation, more exact investigations have been carried on with the same view by others, especially by Lavoisier and Seguin. (*Mém. de l'Acad. des Sc.* 1790.—*Ann. de Chim.* t. 90.) The result of their inquiries was, that during a state of rest the average loss by cutaneous and pulmonary exhalation in a minute is from seventeen to eighteen grains,—the minimum eleven grains, the maximum thirty-two grains. To ascertain the amount of the cutaneous and pulmonary transpiration separately, Seguin enclosed his body in a bag or dress of silk covered with elastic gum, open at the top and provided with a copper mouth-piece. The bag, or dress, being closed by a strong band above, and the mouth-piece adjusted and gummed to the skin around the mouth, he was weighed, and then remained quiet for several hours, after which time he was again weighed. The difference in the two weights indicated the amount of loss by pulmonary exhalation. Having taken off the air-tight dress, he was immediately weighed again, and a fourth time after a certain interval. The difference between the two weights last ascertained gave the amount of the cutaneous and pulmonary exhalation together; by extracting from this the loss by pulmonary exhalation alone while he was in the air-tight dress, he ascertained the amount of cutaneous transpiration. The repetition of these experiments during a long period with great care afforded the following results:—

1. However much the quantity of the food may vary, the weight of the body, if not subjected to exertion, returns in twenty-four hours to about the same standard; so that,
2. If under otherwise similar circumstances the quantity of the food varies, or if, the quantity of the food remaining the same, the loss by exhalation is different, the solid and fluid excretions are proportionably increased or diminished.
3. When digestion is imperfect, exhalation is less active.
4. Digestion being good, the quantity of the food has no great influence on the amount of exhalation.
5. The exhalation is least abundant immediately after food is taken.
6. But the greatest loss of weight from exhalation takes place during digestion.
7. The maximum loss by exhalation, cutaneous and pulmonary, in twenty-four hours, is 5 lb.; the minimum, 1 lb. 11 oz. 4 dr.
8. The cutaneous transpiration is influenced both by the state of the atmosphere and by the state of the body itself.
9. The mean loss by exhalation in a minute is 18 grains, of which 11 grains pass off by the skin, 7 by the lungs.

Dryness of the atmosphere has the effect of increasing the exhalation from the skin and lungs, which process has a cooling influence; while a great elevation of the external temperature is attended with a contrary result.* The cutaneous exhalation is more rapid when the surrounding air is in motion, and when the atmospheric pressure is not great. M. Edwards makes a distinction between the exhalation which is the result of mere physical evaporation, and which would take place in dead bodies under the same circumstances, and that which depends on a vital function; and he calculates that when the temperature of the atmosphere is not above 68° Fahr., the vital transpiration contributes only $\frac{1}{8}$ to the total sum of culaneous exhalation. The product of the physical evaporation is nearly pure water, that of the organic transpiration contains animal matters: the former is suppressed when the air is saturated with moisture; the latter, when the body is exposed to cold. The pulmonary exhalation is, according to M. Edwards, solely the effect of evaporation, which undergoes diminution in an air saturated with moisture, though it be of the same or of a higher temperature than the body. The different states of external temperature affect so much the function of exhalation, that we must extract the most important results of Edwards' researches on the subject. The temperature being the same, water is a better conductor of caloric than watery vapour, and vapour than dry air; and hence the last is, *cæteris paribus*, supported by the animal body longer without inconvenience. Moist and warm air is more heating, because it communicates its caloric more readily to the body, and because the physical evaporation is not so free in it as in dry air. A warm atmosphere saturated with water in a gaseous form, particularly if in the form of vapour, excites a more active vital transpiration than dry air of the same or even of a higher temperature. If its temperature is lower than that of the body, dry air conducts away less heat, and hence is less cooling than moist air, which is a better conductor of caloric.

The components of the cutaneous exhalation are in part matters capable of assuming the form of vapour, such as carbonic acid and water, and in part other matters which are deposited on the skin and become mixed with the sebaceous secretion. Thenard collected the cutaneous perspiration in a flannel shirt which had been previously washed in distilled water, and found it to consist of chloride of sodium, acetic acid, some phosphate of soda, traces of phosphate of lime, and oxide of iron, together with an animal substance. In sweat which had run from the forehead in drops, Berzelius (*Chimie Animale*, p. 324,) found lactic acid, a matter soluble in alcohol (osmazome), a small quantity of a substance insoluble in alcohol, a considerable quantity of chloride of sodium, and muriate of ammonia. The fluid exhaled from the skin has been more recently examined by Anselmino. He placed his arm in a glass cylinder, and closed the opening around it with oiled silk, taking care that the arm touched the glass at no point. The cutaneous exhalation collected on the interior of the glass, and run down as a fluid: on analysing this, he found in it acetate of ammonia and carbonic acid. The exhalation of carbonic acid by the skin had been previously observed by Abernethy and Mackenzie; while Priestley, Fourcroy, and Gordon failed to detect it in their experiments. (*Meckel's Archiv.* iii. p. 608.) Collard de Martigny (*Magendie's Journal*, x. 162,) detected in the cutaneous exhalation both carbonic acid and nitrogen in very variable proportions; they were not constantly present, but were exhaled in great abundance after muscular exertion, and after meals. Sometimes the nitrogen was exhaled alone, as happened in the experiments of Ingenhouss, Trousset, and Barruel. Sometimes the gas was almost wholly carbonic acid, as had been observed by Milly, Cruikshank, Jurine, Abernethy, and Mackenzie. M. Collard states that the nitrogen was more abundant after the diet had consisted principally of animal substances; carbonic acid, when food of a vegetable nature had been taken. M. Collard has collected the gas evolved from the skin by placing over it a glass funnel, closed by a stopper above, and filled with distilled water, and hence infers that the carbonic acid is exhaled in the gaseous form, since it is evolved without the contact of atmospheric air.

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* Edwards, Influence des Agens Physiques sur la Vie. Dr. Hodgkin's translation, pp. 168 to 180.

Anselmino (*Tiedemann's Zeitschrift*, iii. p. 321,) has given the following analysis of the fluid sweat:—In 100 parts of the dried residue there were,

Matters insoluble in water and alcohol (chiefly calcareous salts) . . .	2
Animal matter soluble in water, and insoluble in alcohol (regarded by Anselmino, but in the opinion of Berzelius without sufficient reason, as salivary matter), and salts of sulphuric acid	21
Matters soluble in dilute alcohol (chloride of sodium and osmazome) . .	48
Matters soluble in pure alcohol (osmazome, lactic acid, and its salts,—regarded by Anselmino as acetic acid and acetates)	29
	100

Berzelius mentions sal ammoniac and lactate of ammonia also as ingredients of the perspiration.

In the ashes of the dried residue of the sweat, Anselmino found carbonate, sulphate, and phosphate of soda, and some potash, with chloride of sodium, phosphate and carbonate of lime, and traces of oxide of iron.

In the sweat of the horse, which is known to deposit a white powder, Fourcroy found urea, but Anselmino could not detect it.

Several parts of the body afford a perspiration with peculiar properties, due perhaps to the secretion of the sebaceous follicles. Thus the perspiration of the axillæ is ammoniacal, and that of the genital organs contains butyric acid. Several animals, again, and many men, have a perspiration of a peculiar odour; in animals, however, this odour frequently arises from the products of special glands,—for example, of the anal glands.

The *purpose of the cutaneous exhalation* is not elucidated by its analysis, for the matters met with in it are also constituents of the urine. Since, however, as Seguin's experiments show, its quantity bears so close a relation to that of the food, and also to that of the other excretions, we can in some measure understand how its sudden suppression, by disturbing the normal composition of the circulating fluids and their distribution in the body, may give rise to great disorder of the animal economy. The agency of the transpiration in preserving the body under the influence of high temperatures, has been already explained. (See page 81.)

The cutaneous exhalation and sweat are true secretions; they are not the result of the mere evaporation of those ingredients of the blood which are capable of taking the form of vapour. This is proved by the fact that in some diseases the perspiration is quite arrested, although the temperature of the skin is elevated; such, for example, is the case in many febrile diseases in which the influence of the nerves on the skin is in a state of depression. Moreover, an especial relation exists between the cutaneous exhalation and the urinary secretion; it would appear, indeed, that the skin has the office of separating from the blood those matters more particularly which, at the temperature of the body, take a gaseous form, while the kidneys remove from it the more liquid excreta. But there is another relation, that of alternation of action, between the skin and kidneys. When the urine is secreted in excessive quantity, as in diabetes, the skin is dry. In hot seasons and in warm climates the urinary secretion is less abundant, the cutaneous secretion more so; in winter the reverse is the case; and in diseases the same alternation of action is observed. But the cutaneous secretion is modified not only by its antagonism with other secretions, (see page 451,) but also by many other causes, of which some have their seat in the skin itself, others are dependent on its sympathy with other organs. With regard to the first kind of these causes, it may be remarked, that gentle stimulants applied to the skin itself,—for example, hot baths, —or acting on it through the medium of the blood,—as diaphoretics, —increase its secretion; but that if the irritation of the skin is raised to too great a degree, it becomes red and hot, and its perspiration ceases,—the secretion of the skin, like that of most other parts, being also wholly arrested by inflammation. Hence extensive inflammations of the skin, by arresting its secretion, and thus disturbing the balance in the distribution of the circulating fluids, have a tendency to excite antagonistic actions of a morbid nature, such as inflammations of the mucous membranes. Extensive burns have been observed to be followed by inflammation of the mucous membrane of the intestines or lungs; and in the exanthematous diseases, in which a morbid matter is excreted by the skin, the danger of the supervention of internal inflammation becomes more imminent, not merely in proportion to the suppression of the process by which the morbid matter is eliminated from the blood, but also in proportion to the violence of the inflammation by which the function of the skin is arrested.

The action of the skin is very much modified likewise in accordance with the states of the nervous and vascular systems.

In febrile affections the secretion of the skin and mucous membranes diminishes in proportion as the influence of the nervous system in these parts is depressed. In other states that are not febrile, on the contrary, a sudden withdrawal of nervous energy, such as takes place in syncope and during the sway of depressing passions, gives rise to a profuse cold sweat. The conditions on which these great changes in the cutaneous secretion under certain circumstances depend, have not at present been submitted to a satisfactory physiological investigation.

2. *The Secretion of Urine.*

The urinary secretion is the means of carrying out of the system decomposed and effete animal matters, such as urea and uric acid,—the essential components of the urine,—superfluous saline matters, and, either in an altered state or in their original condition, foreign matters which have accidentally entered the circulation.

The urine is an excretion met with through a great extent of the animal scale. Even insects secrete uric acid by the biliary or rather Malpighian vessels. Uric or lithic acid has indeed been found in entire insects; thus Robiquet (*Annal. de Chimie*, 76,) detected it in cantharides, and it has hence been inferred that this acid is distributed generally throughout their body. But, in analysing the entire body of an insect, the contents of the above-named vessels are necessarily included. There is a secretion of urine in the Mollusca likewise. Jacobson has detected uric acid in the secretion of the saccus calcareus (l'organe de la viscosité, Cuvier) of snails, the efferent duct of which, running by the side of the rectum, terminates close to the anus. (*Meckel's Archiv.* vi. 370.)

The urine. (*After Berzelius, Woehler,* and *Liebig.*) The urine of the human subject is transparent, amber-coloured, and of an aromatic odour; and has a bitter taste, and a strong acid reaction. The urine of oxen, horses, rabbits, and several other herbivorous animals, is alkaline; though in some it is acid in the perfectly fresh state. The urine of herbivorous Mammalia is more turbid and often viscous, and undergoes decomposition less rapidly than the urine of Carnivora. The specific gravity of human urine varies between 1·005 and 1·030; in some diseases, particularly in diabetes, it is occasionally as high as 1·050. The urine occasionally becomes turbid in cooling, and deposits in such cases a grey or pale red sediment, which is redissolved when the fluid is heated. After exposure to the air for a few days, the urine acquires an ammoniacal odour and an alkaline reaction; and there forms on its surface a white slimy pellicle, in which, as well as on the inner surface of the vessel, small white crystals of phosphate of ammonia and magnesia show themselves. (*Berzelius, Chimie Animale*, p. 342.)

a. Essential constituents of urine.—Besides the mucus of the urinary passages, which is rarely visible in the excretion, Berzelius enumerates the following as essential ingredients:

Water, ...	933·00
Urea, ...	30·10
Free lactic acid, lactate of ammonia, osmazome soluble in alcohol, and extractive soluble in water, ...	17·14
Lithic acid, ...	1·00

Mucus of the bladder,	0·32
Sulphate of potash	3·71
Sulphate of soda,	3·16
Phosphate of soda,	2·94
Biphosphate of ammonia,	1·65
Chloride of sodium,	4·45
Muriate of ammonia,	1·50
Phosphate of lime and magnesia,	1·00
Silica,	0·03
	1000·00

The quantity of urea and lithic acid secreted within a given time is, in the same individual, according to Lecanu, (*Comptes Rendus*, Juillet, 1839,) constantly the same; while the salts of the sulphuric, phosphoric, and muriatic acids are secreted in different quantities at different times in the same person.

I. *Urea.*—This substance was discovered in the urine by Cruikshank. It is procured by evaporating urine carefully to the consistence of honey, acting on the inspissated mass with four parts of alcohol, then evaporating the alcoholic solution, and purifying the residue by repeated solution in water or alcohol, and finally allowing it to crystallise.[*] The urea appears in the form of delicate silvery acicular crystals; of long, narrow, four-sided prisms; or, when in the impure state, of scales. It is colourless when pure; when impure, yellow or brown: is without smell, and of a cooling, nitre-like taste; has neither an acid nor an alkaline reaction, and deliquesces in a moist and warm atmosphere. At 59° Fahr. urea requires for its solution less than its weight of water, and is dissolved in all proportions by boiling water; but it requires five times its weight of cold alcohol for its solution. It is not precipitated by tannin. At 248° Fahr. it melts without undergoing decomposition; at a still higher temperature ebullition takes place, and carbonate of ammonia sublimes; the melting mass gradually acquires a pulpy consistence; and, if the heat is carefully regulated, leaves a gray-white powder, cyanic acid, which is likewise formed and sublimes when uric or lithic acid is submitted to dry distillation. Urea forms compounds with both acids and bases, without neutralising them. It is remarkable that the presence of urea causes sal ammoniac to crystallise from its solutions in cubes, in place of octohedrons; and muriate of soda to crystallise in octohedrons, in place of cubes. Nitric acid combines with urea, and precipitates it from its concentrated watery solution. Urea contains more nitrogen than any other animal product. Dr. Prout found it to be constituted of

Nitrogen,	46·65
Carbon,	19·97
Hydrogen,	6·65
Oxygen,	26·65

Woehler has discovered that urea may be formed artificially. (See page 15.)

We owe to Prevost and Dumas the knowledge of the important fact, that, after both kidneys have been extirpated, urea can be detected in the blood; whence it may be inferred, that the reason of this substance not being found, at least in large quantity, in the blood in the healthy state, is, that it is excreted from it as soon as formed. Their discovery has been confirmed by Vauquelin and Segalas, by Mitscherlich, and by Tiedemann and Gmelin.*

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[*] For an account of other methods of procuring it, consult Gmelin's Chimie, iv. 1014, and Berzelius, loc. cit. p. 370.

The source of the urea—the organ from which it enters the circulation—is unknown. It can at present merely be asked, by way of conjecture, whether the urea may not be generated in the lungs during the chemical process which the blood undergoes in respiration, and by which higher organic compounds are formed. It may, however, be produced in other parts also during the conversion of the new nutrient materials into the proper components of the organic fluids. The important question, whether the urea is formed in consequence of the decomposition of that animal matter only which has already been organised, or whether it is derived from the nutriment newly introduced into the blood, being in the latter case a useless product of digestion, has been already discussed. To determine it, it would be necessary to keep animals without food, then to extirpate the kidneys, and to examine the blood to see if it contained urea. This experiment has been performed by M. Marchand.

In several diseases the urine contains no urea; for instance, in hysterical attacks, in which the secretion becomes very watery. The organic matters are then wanting; so that the urine contains only the saline ingredients. In diabetes mellitus, the urine contains, in place of urea, sugar (the sugar of grapes), and the urea reappears in proportion as the quantity of the sugar diminishes. Here, then, an ordinary constituent of the urine, which contains so large a proportion of nitrogen, is replaced by a substance into the composition of which nitrogen does not enter at all; for the sugar of the urine is, according to Dr. Prout, constituted of

Carbon	39.99
Hydrogen	6.66
Oxygen	53.33

It appears, however, from the experiments of Dr. Henry, Mr. Kane, and Mr. M'Gregor,† that urea not only is present in diabetic urine, but exists in it in at least its natural quantity; and the observations of the last-named gentleman tend more especially to show that the quantity of urea and that of the sugar in the urine in this disease are quite independent of each other.

In diabetes insipidus, in which the urine contains no saccharine matter, the place of the urea is supplied by another substance, which is in great part soluble in alcohol, and agrees in its characters with osmazome. In anasarca, deficiency of urea in the urine is supplied in equal proportion by the presence of albumen, and the urine is then coagulable by heat. This albuminous state of t pecially frequent in dropsy attending the degener pointed out by Dr. Bright. According to Dr. Ch relation subsists between the quantity of albume that of the urea in this disease. On the other han (*Müller's Archiv.* 1837, p. 440,) and Dr. Christison have se times found urea in the fluid of dropsical swellings; and it has been detected by Dr. Bostock and Dr. Christison in the blood in the same disease. The presence of albumen in the urine, with deficiency of urea, has likewise been observed in cases of chronic inflammation of the liver with constant dyspepsia,[*] as well as towards the termination of all diseases producing emaciation.

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* Tiedemann's Zeitschrift, v. 1. See also Nysten, Recherches de Chimie et de Physiol. Pathol. Paris, 1811, p. 263. Meckel's Archiv. ii. 678.

† See London Med. Gazette, vol. xx. pp. 221 and 268. See also Dr. Willis's excellent treatise on Diabetes, in his work on Urinary Diseases.

2. *Uric or lithic acid.*—We obtain lithic acid from the sediment of human urine, or from the urine of birds and serpents, by dissolving the secretion evaporated to dryness in warm water, filtering the solution, and precipitating by means of muriatic acid. Lithic acid crystallises in the form of delicate, white,—or, when impure, yellow or brownish,—scales; it is devoid of taste and smell, reddens moistened litmus paper, and requires, according to Prout, more than 10,000 times its weight of cold water for its solution, but somewhat less boiling water. It is insoluble in alcohol and ether. By dry distillation it is decomposed; carbonate of ammonia being first sublimed, afterwards hydrocyanic acid in large quantity, and a brown empyreumatic oil, and, lastly, a crystalline substance, cyanic acid, according to Woehler,[†] with which a quantity of urea is mixed. The elementary composition of lithic acid has been stated by Dr. Prout to be—

Nitrogen, in his first analysis	40.25	in a later analysis	31.12
Carbon	34.25		39.87
Hydrogen	2.75		2.22
Oxygen	22.75		26.77

Urine, while warm, holds in solution much more lithic acid than an equal quantity of boiling water will dissolve, and this has induced Dr. Prout to think that in the urine the acid is in the state of lithate of ammonia. The lithic acid which is precipitated during the cooling of the urine is, however, in the free state. Duvernoy[‡] contends that it is held in solution in warm urine by means of the colouring matter. The precipitate of lithic acid is at first powdery and grey, but assumes by degrees a rose-red colour, and crystallises as it dries. The red or brickdust tint of lithic acid is due to a colouring matter which is combined with it: in intermittent fevers this red colour is unusually deep. Berzelius regards it as still very doubtful whether, or not, the red colour of the precipitate in the urine in fevers is dependent on the presence of purpurate of ammonia.

Duvernoy detected no essential difference between the deep-coloured red urine and the urine of the crisis of fever, which deposits a sediment. Both have a stronger acid reaction, and a redder colour, and contain a larger quantity of lithic acid than natural. The critical urine merely had a larger proportion of the acid, and deposited it more readily.

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[*] Rose and Henry, in Meckel's Archiv. ii. 642. Dr. Graves, Dublin Journal, vol. vi.

[†] Poggendorf's Annal. xv. 529.—Berzelius's Chimie Anim. p. 348.

[‡] Untersuchungen über den Menschl. Urin. Stuttg. 1835, 8.

Liebig and Woehler* have discovered that lithic acid contains urea in a peculiar state of combination; or, at all events, that by decomposition it yields urea, with several other products. Lithic acid brought to the consistence of a thin pulp with water, was heated nearly to the boiling point, and then superoxide of lead was added, which gave rise to the development of carbonic acid gas. The fluid separated from the mixture by filtration, yielded, on cooling, colourless or yellowish, brilliant, hard crystals of allantoic acid, the substance found in the fluid of the allantois of ruminants. The supernatant liquid being poured off, evaporated, and again cooled, crystals of urea formed in it. The superoxide of lead was converted into a white mass, consisting of oxalate of lead. The products of this decomposition, then, are allantoic acid, or rather, since it is not an acid, allantoin, urea, oxalic acid, and carbonic acid. Allantoin is composed of:

Carbon	30.66 or	4 atoms
Nitrogen	35.50	4
Hydrogen	3.85	6
Oxygen	30.08	3

It may therefore be regarded as a compound of four atoms of cyanogen, with three atoms of water. Its elements require three atoms of water to give it the composition of oxalate of ammonia, into which it is converted by the action of alkalies and sulphuric acid. If now we admit, with Liebig and Woehler, that the urea pre-existed in the lithic acid, by substracting from

	Carbon.	Nitrogen.	Hydrogen.	Oxygen.
1 atom lithic acid	10	8	8	6
1 atom urea	2	4	8	2
	—	—	—	—
we shall have as remainder . . .	8	4	0	4

which are the elements of four atoms of cyanogen, and four atoms of carbonic oxide. These chemists therefore regard lithic acid as a compound of urea with a substance composed of cyanogen and carbonic oxide, which in the above process is converted by the action of the superoxide of lead into oxalic acid and allantoin.

The urine of many animals differs from that of the human subject in respect of the quantity of the urea and lithic acid. The urine of carnivorous Mammalia contains both urea and lithic acid. Vauquelin and Boindet (*Froriep's Notiz.* No. 272,) have denied that it contains any lithic acid, but Hieronymi (*Jahrb. der Chem. u. Phys.* 1829, iii. 322,) obtained some of this acid from urine of the feline tribe. In 100 parts of urine he found 13.220 parts of urea, with osmazome, and free lactic acid, and 0.022 parts of lithic acid. The urine of herbivorous animals contains urea, but no lithic acid; the place of which, in the urine of graminivorous animals, is supplied by hippuric acid, forming hippurates. The urine of birds contains abundance of superlithate of ammonia; that of carnivorous birds is said by Coindet to contain urea, which does not exist in the urine of birds which feed on vegetable substances, although the superlithate of ammonia exists in the latter also. Lithic acid constitutes $\frac{1}{80}$ of the weight of the urine of the ostrich. The consistent, pulpy, urinary secretion of birds owes its white colour to the presence of lithate of ammonia. It appears, that the presence or absence of urea and lithic acid (of which the former contains 46, the latter 40 per cent. of nitrogen) stands in no constant relation to the nature of the food of the animal. The only fact bearing on the point is, that in herbivorous Mammalia the lithic acid is replaced by hippuric acid, which contains only 7 per cent. of nitrogen. It is stated likewise by Chevreul, that when dogs are kept for a long period on vegetable food, their urine becomes like that of Herbivora, in ceasing to contain any lithic acid or phosphate of lime. (*Huenefeld, Physiol. Chimie,* i. 150.)

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* Poggendorf's Annal. p. 41, 561; and the British Annals of Medicine for Sept. 16, 1837.

In gout the urine is usually very acid, and deposits an abundant sediment, and also contains a greater proportion of lithic acid than in any other disease; although during the febrile state which accompanies the paroxysms of gout, as in other cases of fever, the urine is deficient in that acid. (*Berzelius, Chimie Anim.* p. 404. See also *Nysten, loc. cit.*) The abundance of lithic acid in gouty habits, however, is likewise shown by the concretions which form in the joints, and which consist of lithate of soda, with some lithate of lime. It is not improbable that the perspiration likewise of patients labouring under gouty and calculous diseases contains lithic acid.

All the foregoing circumstances render it very probable that the source of the lithic acid lies much deeper than the point of its excretion, and that its production is intimately connected with the nature of the food, and with the process of sanguification, since its proportion in the urine diminishes when the food consists wholly of vegetable substances.

In diabetes mellitus, lithic acid is still present in the urine, (*Woehler, Berzelius's Jahresb.* vi. 283,) and, according to M. Wittstock, hippuric acid also.

3. *Hippuric acid* is met with in the urine of young children (?), and of graminivorous animals, in the state of hippurate of soda. It is procured by evaporating the urine, and precipitating by muriatic acid; it forms long, transparent, four-sided prisms, is without taste, or is but slightly bitter, and reddens moistened litmus paper. Gmelin has classed it as a modification of benzoic acid among the substances which contain no nitrogen; but Liebig regards it as a peculiar acid, and not as a mere compound of benzoic acid with animal matter; and, since it gives out ammonia when decomposed, it must contain nitrogen. It is difficult of solution in cold water, more soluble in boiling water; alcohol dissolves it in much greater proportion, ether in less. Its composition, according to Liebig, is,

Carbon,	63.032
Hydrogen,	5.000
Nitrogen,	7.337
Oxygen,	24.631

4. *Lactic acid* is, according to Berzelius, a general product of the spontaneous decomposition of animal matters within the body; it is generated in large quantity in the muscles, is saturated by the blood and its alkali, and is carried out of the system in the acid urine of man and animals. It is the principal cause of the acidity of the urine, although this secretion contains likewise superphosphates of ammonia and lime.

5. *Salts of the urine.*—The secretion of the human kidney contains both sulphates and phosphates. Berzelius supposes that the acids in these salts are the product of the chemical action of the kidneys, because in the other fluids of the body there are merely traces of sulphates, and but a small quantity of phosphates, while the urine abounds with both; but his reasons do not justify the conclusion which he draws. Berzelius imagines that the sulphur which enters into the composition of the fibrin, albumen, &c. is converted in the kidneys into sulphuric acid, while the other elements unite to form ammonia, urea, &c. He holds the same opinion with regard to the phosphorus which exists in several of the solids of the body. In the urine of herbivorous animals the place of the phosphates is supplied by salts of carbonic acid. The experiments of Berzelius and Woehler prove that the urine does not constantly hold carbonic acid gas in solution. The silicic acid seems to be derived from the water taken as drink. The bases of the salts of the urine are potash, soda, ammonia, lime, and magnesia; the salts are chloride of potassium, muriate of ammonia, phosphate of lime (a supersalt, while the phosphate of the bones is a subsalt), and a small quantity of fluate of lime.*

Nysten (*Loc. cit.* and *Meckel's Archiv.* ii. 648,) has investigated the differences between the urine secreted subsequently to the digestion of food,—"urina chyli,"—and the limpid, tasteless urine secreted after fluids have been taken,—the "urina potûs;" the latter he finds to contain thirteen times less urea than the former, four times less of the sulphates, muriates, and phosphates of soda and ammonia, and sixteen times less lithic acid. Urine secreted during the existence of inflammation (peritonitis) contained three times more urea than the urina chyli, more of the soluble salts, and a large quantity of albumen, which is not a constituent of healthy urine. In the cold stage of fever the exhalation from the skin is diminished, and the urine becomes more watery; but this does not arise, Berzelius thinks, from the water which ought to pass off by the skin being now got rid of through the kidneys, for the actual quantity of the urine itself is less at this time. In the hot stage, the colour of the urine becomes darker; and the chloride of silver, which produces no precipitate as long as the urine preserves its acid reaction, now throws down a sediment. As the fever advances, the urine becomes more saturated, and begins to afford a precipitate with alum, and at last with nitric acid, showing an increase in the quantity of albumen which it contains. (*Berzelius's Chimie Animale*, p. 402.) As the fever declines, the free acid reappears in the urine, which at the same time deposits a sediment in cooling, and this is usually denominated a crisis by the urine. According to the observation of Duvernoy, however, the urine is acid during the whole course of the fever. Berzelius remarks, that the sediment of the crisis of fever is nothing more than the ordinary sediment, with a rather larger quantity of the red colouring matter, and sometimes some nitric acid in an unknown state of combination. In fevers of a periodical type the urine in each paroxysm passes through the three states just described.

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* For a more detailed account of the saline substances in the urine, as well as of its doubtful constituents, and the extractive matter soluble in pure alcohol, see the Chimie Animale of Berzelius. The variations in the proportion of the solid constituents of the urine dependent on the food have been investigated, without reference to their chemical nature, by Chossat. (Magendie's Journal, v. 65—225.) On the subject of the urine and its secretion consult Meckel's Archiv. ii. 629—704, where the observations of different authors are collected; and Dr. Prout's work on Diseases of the Urinary Organs; also Dr. Willis's work already referred to, Amer. edit.

b. Accidental constituents of the urine.—Woehler (*Tiedemann's Zeitschrift*, i. *Band*,) has performed a series of careful experiments relative to the passage of substances from the intestinal canal into the urine. The following are the results which he obtained:

1. Matters which, when taken into the stomach, cannot afterwards be detected in the urine: iron, lead, alcohol, sulphuric ether, camphor, oil of Dippel, musk, and the colouring matters of cochineal, litmus, sap-green, and anchusa root. After fluids impregnated with carbonic acid have been drunk, this gas cannot be detected in the urine in larger quantity than before.

2. Matters which pass off by the kidneys after suffering change or decomposition: ferrocyanuret of potassium or prussiate of the peroxide of iron and potash (blausaures eisenoxydkali), converted into a compound of the same elements with a less proportion of cyanogen, or prussiate of the protoxide of iron and potash (blausaures eisenoxydulkali); the compounds of potash and soda with the tartaric, citric, malic, and acetic acids changed into carbonates; the hydrosulphuret of potassium for the most part converted into sulphate of potash; sulphur in the state of sulphuric acid, and sulphuretted hydrogen; iodine in the state of a hydriodate; and the oxalic, vinic, gallic, succinic, and benzoic acids in combination with alkalies. Hence the inutility of giving acids as remedies for calculous disorders.

3. Matters which pass unchanged into the urine: carbonate, chlorate, nitrate, and sulphocyanate of potash, hydrosulphuret of potassium (which is in greater part decomposed), ferrocyanuret of potassium with the smaller proportion of cyanogen or prussiate of the protoxide of iron and potash (blausaures eisenoxydulkali), borax, muriate of baryta, silicate of potash, tartrate of nickel and potash, and many colouring matters, such as those of soluble indigo, or sulphate of indigo, gamboge, rhubarb, madder, logwood, red

beet, whortleberries, mulberries, cherries; many odoriferous matters also, in part changed, such as oil of turpentine (producing the odour of violets in the urine), the odorous principles of juniper, valerian, assafœtida, garlic, castor, saffron, opium, the intoxicating principle of the agaricus, muscarius, and, in the state of disease, fatty oil.

All substances excreted with the urine must be in solution, they cannot be in the state of granules.*

The matters which do not pass off with the urine are either eliminated from the system in other ways,—for instance, by exhalation from the surface, as is the case with camphor,—or reduced to an insoluble condition in the intestinal canal itself. Woehler directs attention to the fact, that the salts which are excreted with the urine generally increase the action of the kidneys. Many other medicines which are called diuretics, such as digitalis, are, he observes, termed so incorrectly; thus the action of digitalis consists in the removal of the cause of dropsy, the fluid being then carried off in the usual way; so that it is not more a diuretic than quinine given for the relief of the dropsies which are produced by intermittent fever.

The office of the kidneys, according to Woehler's researches, does not merely consist in the excretion of urea and lithic acid; but that all soluble and other matters which are not gasiform and do not suffer decomposition in the system, and more especially the superfluous water, are got rid of by means of them. If the excretion of water by the kidneys is lessened on account of that fluid being deposited in other parts of the body, as in dropsy, the urine acquires a deeper colour, which indicates merely that less water is excreted.

The carbonates of the alkalies taken by the mouth render the urine alkaline, and dissolve the lithic acid; their exhibition is a tolerably certain means of counteracting the lithic acid diathesis; the vegetable acids and their salts with the alkalies, being converted into alkaline carbonates in their passage through the body, they may likewise be used with effect for the same purpose. This plan of treatment is, however, only applicable in cases of gravel, or when the calculi are small; for when there are large stones in the bladder, an alkaline state of the urine renders the earthy phosphates insoluble, and may cause them to be deposited as a new crust around the original calculus. (*Woehler, loc. cit.* p. 317.)

The excretion of superfluous water from the blood by the kidneys appears to take place with extreme rapidity, nearly keeping pace with the absorption of watery fluids from the other parts of the body into the blood, which is thus enabled to maintain its normal composition.

The time occupied by the transit of different substances from the intestines into the blood, and thence into the urinary secretion, has been mentioned at page 255. Westrumb detected prussiate of potash in the urine within a period varying from two to ten minutes from the time of its introduction into the stomach. Stehberger (*Tiede-*

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* I have already expressed my disbelief in pus being separated from the blood by secretion from the kidneys.

mann's Zeitschrift, ii. 47) has instituted experiments with reference to this question in a boy, who had inversio vesicæ. The following are the results:—

Name of Substance.	*Time at which first detected in the urine.*	*Time at which it was excreted in greatest quantity.*	*Time at which it ceased to be perceptible.*
Madder after the lapse of	15 min.	1 hour	9 hours.
Indigo	15	1¼	4½
Rhubarb	20	1⅓	6⅓
Gallic acid	20	2½	11
Decoction of logwood	25	1¼	6¾
Cols principle of whortleberries	30	2	8¾
" " black cherries	45	1¼	
Astringent principle of uva ursi	45	1¾	7⅓
Pulp of cassia fistula	55	4	24
Ferrocyanuret of potassium	60	0	3¾
Inspissated juice of elder	75		

The urine collects in the urinary bladder, the sphincter of which, like that of the anus, is ordinarily in a state of contraction. When the quantity of the urine has increased to a certain degree, the action of the sphincter becomes feeble, and contractions of the fundus of the bladder take place. The expulsion of urine may, however, be opposed at will by means of the musculus pubo-urethralis, (Wilson's muscle,) and perhaps likewise by a voluntarily increased contraction of the sphincter. The voluntary expulsion of the urine is effected by the simultaneous action of the diaphragm and abdominal muscles, which diminishes the capacity of the abdominal cavity. The contractions of the urinary bladder are not always subject to the will; but, nevertheless, when the bladder is affected by the gradually increased stimulus of the accumulated urine, we seem to acquire some voluntary influence over it.—Erection, and the act of expulsion of the urine, are here excluded from consideration. Paralysis of the lower part of the spinal cord is attended with incontinence of urine.

SECTION IV.

OF NUTRITION AND GROWTH.

CHAPTER I.

Of Nutrition.

a. Of the nutritive process.—The process of nutrition is not an object of microscopic observation. The arrest of red particles of the blood in the capillaries, and their union with the substance of the part, described by Doellinger and Dutrochet, I have never seen; and the theory, that nutrition is effected by the direct union of the red particles of the blood, or of their nuclei, with the tissues, is, in my opinion, decidedly erroneous. The perfection at which micrometry has arrived, and the use of good instruments, have made us now so well acquainted with the physical properties of the organic tissues, that we are enabled to refute the above theory, by merely comparing with precision the size of different parts.

Microscopic examinations, if intended to serve as the basis for scientific researches and comparisons, must not consist merely in the direct measurement of each object; a much more important and essential mode of investigation is the comparison of the object to be measured with some other body that can be taken as a standard. Thus, for instance, in measuring the size of the muscular or nervous fibrils, they should be placed under the microscope, together with red particles of human blood, and both should then be observed at the same time. The admeasurements of the red particles of human blood, as stated by Kater, Wollaston, Prevost and Dumas, Weber, Wagner, and myself, agree so nearly, that their diameter may with great certainty be stated at $\frac{1}{4000}$ of an inch English. We have thus a certain standard of measurement. As standards of comparison, I employ the red particles of human blood, easily obtained by slightly scratching the skin, those of frog's blood which are about four times larger in diameter, and the nuclei of these latter bodies, obtained by the action of acetic acid, which measure about ¼th or ⅓d the long diameter of the entire red particle. We have already seen, (at pages 20–21,) that the ultimate fibres of muscles and nerves do not correspond in size either with the red particles or their nuclei. Moreover, the nuclei of the red particles of the frog's blood are not globular but elliptic in form, and those of the red particles of the salamander's blood are even flattened. How, then, can they compose the ultimate fibres of nerves and muscles? We shall see that the form of these tissues affords no grounds for such an opinion. And the recent observations of Schwann and others, on the mode of growth of all the elementary parts of the body, prove it to be incorrect.

The most minute capillary vessels do not ramify upon the primitive fibrils of nerves and muscles; these fibrils are too fine to receive vessels, and are, in fact, more minute than the capillary vessels themselves, which measure from $\frac{1}{4000}$ to $\frac{1}{1850}$ of an English inch in diameter. Nutrition, therefore, must be effected through the coats of the capillary vessels, and the process consists in the fluid parts of the blood permeating the parietes of the capillaries, while the solid particles are visibly carried onwards into the veins. The most important materials for nutrition are the albumen and fibrin dissolved in the liquor sanguinis. A portion of these matters permeate the parietes of the capillaries, and are imbibed by the tissues; and what is effused over and above the quantity required for their nutrition, is taken up by the absorbent vessels, and carried again into the blood. It is here of importance to know that the capillaries really have solid parietes; the proofs of which were seated at page 224. Nothing can pass from the blood to the tissues, or from the tissue to the blood, without permeating, in the fluid state, the walls of these vessels. The hypothesis of the blood flowing in simple canals excavated in the substance of the organs, appears at first sight calculated more easily to explain the problem of nutrition, but is found on examination to be untenable. The permeable parietes of the capillaries are, in fact, no impediment to the process of nutrition, which appears to consist in matters dissolved in the blood being attracted from it by the organic particles contained in the meshes of the capillaries, while at the same time the old materials of the particles are returned into it. Wildbrand certainly did not employ the microscope when he formed his hypothesis of the metamorphosis of the blood in the small vessels.

It is not known whether the parts which appear to contain colouring matter, as, for instance, the muscles, derive it from the blood by the solution of a part of the colouring envelope of the red particles, or whether this matter, which becomes still more highly coloured by the action of the atmosphere, is formed in the muscles themselves. But, however this may be, the red particles themselves do not unite in substance with the tissues. They certainly perform some very important office in the animal economy. In their passage through the lungs they acquire the bright arterial colour, and in their subsequent transit through the capillaries of the body a reciprocal action takes place between them and the component particles of the organs, by which they lose this bright colour, becoming again of a dark red; but they still move on in a continuous current, exerting their influence on the tissues in their transit through them, without being arrested by them. In each circuit of the blood, which occupies less than three minutes, they undergo two changes of colour; one from dark red to bright scarlet in the lungs, and another from scarlet to dark red in the capillaries of the body. In twenty-four hours each of these changes takes place about 480 times. In their arterialised condition the red particles exert on the organs of the body, and especially on the nerves, a stimulating action, which is essential to life, but which is a very different thing from contributing new nutritive matter. Dutrochet believed that the red particles have peculiar electric properties, an opinion which we have elsewhere refuted. The colourless "lymph globules" which are seen rolling slowly along the inner surface of the capillary vessels, may possibly serve some purpose in the process of nutrition. Prof. E. H. Weber has observed, that under certain circumstances the red particles of the blood circulating in the capillaries of the frog or tadpole attach themselves to the sides of the vessels, lose their red colour, and then roll along the inner surface of the capillaries in the form of colourless lymph globules.

In the process of nutrition is exemplified the fundamental principle of the organic assimilation. Each elementary particle of an organ attracts similar particles from the blood; and, by the changes it produces, causes them to participate in the vital principle of the organ itself. Nerves form nervous substance, muscles muscular substance, even morbid structures have the assimilating power;—warts on the skin grow with their own peculiar structure; in an ulcer the base and border are nourished in a way conformable to the mode of action and secretion determined by the disease; and the assimilation of the nutrient materials of the blood to form an organ with diseased action may induce the destruction of the life of the animal.

The proximate elements of the tissues exist in part ready formed in the blood. The albumen which enters into the composition of the brain and glands, and of many other structures in a more or less modified state, is contained in the blood; the fibrin of the muscles and muscular structures is the coagulable matter dissolved in the lymph and blood; the fatty matter which contains no azote, exists in the free state in the chyle; the azotised and phosphoretted fatty matter of the brain and nerves exists in the blood combined with the fibrin, albumen, and cruorin. The iron of the hair, pigmentum nigrum, and crystalline lens, is also contained in the blood; the silica and manganese of the hair, and the fluor calcium of the bones and of the teeth, have not hitherto been detected in the blood, probably from their existing in it in too small proportion. The matters here enumerated are in part attracted from the blood in the state in which they afterwards exist in the organs; while in other instances their ultimate elements are newly combined, so as to form new proximate principles. The opinion that all the component elements of the organs exist previously in the blood in their perfect state, cannot possibly be adopted: the components of most tissues in fact present, besides many modifications of fibrin, albumen, fat, and osmazome, other perfectly peculiar matters, such as the gelatine of the bones, tendons, and cartilages,—nothing analogous to which is contained in the blood. The substance of the vascular tissue, and the different glandular substances, cannot be referred to any of the simple components of the blood. Even the fibrin of muscle cannot be considered as exactly identical with the fibrin of the *liquor sanguinis.* For between coagulated fibrin and coagulated albumen there is scarcely any chemical difference, except in their action on peroxide of hydrogen; and the only very important distinction between the fibrin dissolved in the blood and the albumen is, that the former coagulates as soon as it is withdrawn from the animal body, while the latter does not coagulate spontaneously, but requires a heat of from 158° to 167° Fahr., or some chemical agents, such as acids, concentrated solutions of fixed alkali, or metallic salts; while the fibrin of muscle has in its chemical characters scarcely a greater analogy with coagulated fibrin than with coagulated albumen, and in its vital properties differs from both. The comparison of nervous substance, again, with albumen and fatty matter containing nitrogen and phosphorus, is only justified by the present imperfect state of organic chemistry.

Assimilation, then, does not consist merely in the component particles of the organs attracting the fibrin, albumen, and other materials of the blood which flows through them, adding to themselves the matters similar to their own proximate principles, and changing the composition of those which are dissimilar; but the assimilating particles must infuse into those newly assimilated their own vital properties. Organs may increase in size, independently of assimilation; thus, in inflammation, the albumen and fibrin of the blood accumulate, unassimilated, between the particles of the tissues; and this sufficiently marks the distinction between inflammation and hypertrophy, or increased nutrition. In the pregnant state, the contractile tissue of the uterus increases in bulk by the addition of real contractile particles, duly assimilated to the original tissue, but in inflammation of the uterus nothing of this kind is observed. In inflammation the assimilating power is arrested, the fibrinous fluid of the blood exudes through the membranes, or collects in the interstices of the tissue of the organs: and this matter, therefore, which increases the volume of the inflamed organ is the same, whatever the organ may be; while in the process of nutrition, the components of the blood assimilated by the different tissues are, in each case, differently modified and changed. Inflammation, consequently, is not an increased degree of the plastic or nutritive process. From these considerations, too, it is easy to understand why a stimulus which promotes the action of an organ, is very different from one which excites inflammation. As an argument supporting the incorrect opinion that inflammation is an exaggeration of the nutritive process, it has been urged, that, during the continuance of inflammation in a wound, new substance is formed. But the formation of new organised substance in this case is due to the action of the *vis medicatrix;* while the surface of the wound being subject to constant irritation until cicatrisation is perfected, necessarily continues to be affected with inflammation. In inflammation, as well as in simple hypertrophy, the matter effused by the vessels becomes to a certain extent organised. Nucleated globules or cells, which have been called "exudation-corpuscules," soon appear in it. These cells may undergo no further transformation, and, with the fluid in which they are contained, may constitute pus, or they may become converted into bundles of fibres in the same manner that the fibres of cellular tissue are normally developed from cells. But the tissue which is thus produced appears to be always the same, in whatever structure or organ the inflammation may be seated. Its formation is the cause of the enlargement and induration of organs which have been inflamed; and the tissue of cicatrices is of the same nature. In parts which are undergoing hypertrophy, on the other hand, though the nutritive matter effused assumes first the form of nucleated cells, each tissue exerts a different assimilating influence on it, and causes the transformation of the cells into tissue of its own kind, and not into mere fibrous or cellular tissue.

There are several substances which are known to diminish the activity of the assimilating process, by effecting a change in the composition either of the organ or of the blood. Iodine, for example, when its use is long continued, has a remarkable effect in diminishing nutrition. The neutral salts, mercurial medicines, tartarised antimony, and other substances, have the same effect on the system. The immediate action of these substances is partly to produce a change in the blood, as is evident in the case of the cooling salts, which when added to the blood, even out of the body, deprive it of its property of coagulating, of course by a change produced in the fibrin; and it is on this account that these substances are of importance in checking inflammation.

The circulating fluids—the chyle and blood, sometimes acquire an abnormal composition, either from the new nutrient matters from which they are formed not having their natural healthy composition, or in consequence of the operation of an inoculated virus, as that of syphilis. In all these cases, in which the circulating fluids are diseased, nutrition also suffers. Depositions of morbid matter, inflammations, and sores, occur, as in scrofula, gout, lepra, herpes, scurvy, syphilis, &c. All the diseases here enumerated, although very different in themselves, have the common character of manifesting themselves by the secretion of morbid matters on the skin, by eruptions and sores of the surface, frequently by ulcers of the mucous membranes, and in extreme degrees by morbid affections of the bones. Several medicines which themselves have the power of modifying the assimilating process, (see the observations on alteratives, p. 68,) and which, when long used, also produce ulcers and diseases of the bones,—mercury and antimony, for instance,—are sometimes of service in such diseases, not on the principle that *similia similibus curantur*, but because they produce such an alteration in the composition of the tissues, that the affinities already existing are annulled and new ones induced, so as to enable the vital principle—the power which determines the constant reproduction of all parts in conformity with the original type of the individual—to effect the further restoration and cure: the medicines themselves do not complete the cure. In several of the diseases in which the fluids of the body are in a morbid condition, the lymphatic system—the absorbent vessels and glands—is likewise particularly liable to suffer. Regarding this system in the ordinary way as merely intended for absorption, it is difficult to understand why it should be implicated in many of these diseases, particularly in scrofula. But when it is known that the lymph is almost identical with the liquor sanguinis, both containing fibrin and albumen in solution, and that the lymphatics remove from the tissues that portion of the liquor sanguinis effused into them for the purpose of nutrition, which exceeds the quantity necessary for this object, while, moreover, they have a great share in the conversion of the albumen into fibrin, it is easy to conceive that a change in the composition of the *liquor sanguinis*, causing irritation and inflammation in the capillaries, must also excite irritation in the lymphatics,—the fluid which circulates in them being the same. All the other substances contained in solution in the blood, besides the albumen and fibrin,—the salts, for example,—and their morbid composition, must also have great influence on the state of the lymphatics. When it is not so much the fluid ingredients of the blood that are morbidly changed, as the cruor or red particles, which do not enter the lymphatic vessels, as, for example, in scurvy, these vessels and their glands present less evident appearances of disease. The foregoing remarks are sufficient to show that the future study of the morbid states of the fluids of the body will find a surer basis in the analysis of the lymph and blood which we have offered, than in the older notions regarding these fluids.

The nutrition of all parts of the body in conformity with the original type, presupposes the persistence of that power which originally produced all the distinct parts—all the organs—as "members of one whole," as parts necessary to our idea of the being, and which is present in the germ before any distinct organs are formed, while the animal exists merely "potentially." (See page 31.) Nutrition, then, is the continued reproduction, as it were, of all parts of the animal by this internal power: but in the adult the reproduction can be effected only by the process of assimilation, that is, by the union of new matter with the assimilating parts; while in the embryo, in which no organised "groundwork" as yet exists, the parts are formed—their "groundwork" is in fact created—by the formative power which is still undivided. For although, until the whole body perishes, all the organs are directed by *one* formative principle, which produces the concurrent action of all assimilating tissues; and the operation of which we admire, as the *vis medicatrix naturæ*, in the correction of the subtle material changes which are induced by diseases; yet organised parts of the body once formed cannot in most cases, if wholly destroyed, be again restored by this power.

In some diseases there is such a morbid formation of the animal matter, that the assimilation of the fluids to form the natural elementary tissues of organs is in certain parts of the body wholly arrested; and, on account of the predominance of abnormal affinities, non-analogous tissues, such as cancer and medullary fungus, are formed.

Life is attended with a constant change of the material of the body.—This is proved by new nutriment being required in proportion to the quantity of the excretions. The question, however, presents itself—Do the components of the fluids merely undergo this change, or are the particles of the organised tissues also renewed?

1. *Renewal of the material of the fluids.*—It is most natural to suppose that the change of material takes place primarily in the fluids of the body, and that the fluids only are implicated in the change by which several pounds of nutriment are received daily in place of several pounds of decomposed matters, which are expelled in the cutaneous transpiration, in respiration, with the urine, and other excretions, and that the solids themselves have little share in it. The fluids, while they maintain the life of the body, are constantly undergoing decomposition, and in this respect the animal machine might be compared with other machines,—for example, with the steam-engine, which requires a certain quantity of fuel for the generation of the steam, on which its action depends. There is no doubt that the change of material takes place to the greatest extent in the fluids; it is, indeed, sufficiently proved by the fact that the excretion of urine takes place at very long intervals in reptiles—tortoises, for instance—which are kept without food. It may be supposed that the partial decomposition which the fluids suffer in the performance of their function of supporting life, renders necessary the excretion of the decomposed matters, and the supply of new nutriment.

2. *Renewal of the material of the organised solids.*—There are many phenomena which it appears difficult to reconcile with the idea of the renewal of the animal matter in the organised solids; for example, the preservation of past ideas, which are the result of certain impressions made upon the sensorium. Organic change of the sensorium produces change or diminution in number of the impressions previously accumulated, and annuls the faculty of recalling single chains of ideas, such as, for example, the memory of the structure of languages, and, as it appears, even of particular parts of speech,—substantives, proper names, &c.,—the remembrance of certain places, and of certain periods of past life. How, now, can the existence of memory,—the intellectual life of man,—as a state resulting from past development, be imagined, if a great change in the materials composing the brain and nerves is admitted to take place? This difficulty, however, is got rid of, if we suppose the operations of the mind to be independent of changes in the cerebral substance. On the other hand, we are certainly destitute of proofs that any rapid change of material takes place in the brain.*

In most parts, the nerves excepted, there are many unequivocal signs of the change of material; and the bones themselves, which at first sight appear the most fixed and stable parts of the body, nevertheless exhibit such distinct traces of renewal of their material, as seem to prove that this process is not limited to the fluids of the body, but is a phenomenon which prevails extensively even in the organised solids. Among the evidences of the renewal of the material of bones are the formation of the cells, the development of the frontal and sphenoidal sinuses in childhood, the absorption of bones under the pressure of swellings, the absorption of the alveoli of the jaws, and the thinning of the cranial bones in old age, &c. The enlargement of the cavities of the bone, with enlargement of the whole bone itself, and indeed the mere growth of so solid a body by interstitial assimilation, and the changes that its form undergoes during growth, are not conceivable without a constant removal of osseous particles from certain parts, and the deposition of similar particles at other parts,—consequently not without a change of material. In other parts of the body the proofs of the renewal of the substance are less evident. Such proofs, however, are found in the constant decomposition on the surface of a fungoid growth, such as fungus hæmatodes, concurrently with its reproduction,—in the wasting of the solids of the body during abstinence from food, in atrophy, and in several chronic diseases,—and in the growth, change of form, and wasting of tumours and warts, and their frequently rapid reproduction after previous wasting. The parts removed in these cases must be received either into the blood-vessels or into the lymphatics, when these latter vessels exist in the part. It would be incorrect, however, to regard the lymphatic absorption as the mere resumption of the previously organised particles of the solids into the fluids, and the lymph consequently as a mere solution of the solids; for, if we except its globules, the lymph consists, as we have seen, of liquor sanguinis, and is derived from the part of that fluid which is effused into the tissue of the organ, and is not required for nutrition.

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* The large supply of blood which the brain receives, however, renders it very probable that its component matter does undergo a rapid change. The quantity of blood sent to any part of the body seems to be proportioned to the activity of the organic chemical changes, of which it is the seat; and, where neither secretion nor the formation of new substance is taking place, we must suppose the supply of nutritive fluid to be destined to replace, by new material, the decomposed effete particles. And, in accordance with this supposition, it is found that, *cæteris paribus*, the parts of the body which most readily undergo decomposition after death, as the cerebral substance and muscles, receive the largest supply of blood during life; and, on the other hand, that the most indecomposible structures, as the teeth and horny textures, are not only destitute of vessels, but are little capable of imbibing the nutritive fluids from other vascular tissues.—*Translator.*

The exchange of old for new matter in the solids of the body might be presumed, without other evidence, from the constant changes which are taking place in the form of parts. From childhood upwards the organs are continually changing their form, and this change in the form of the whole organ can only be effected by means of a change in the minute elementary particles of which it is composed. It may be imagined that, in this change the particles absorbed are taken up into the blood, and are soon employed again for the purpose of nutrition at other points. But it still remains for us to inquire, whether there does not exist a process of renewal of the constituent matter of organs, in which the old and decomposed materials are taken up into the blood for the purpose of being expelled from the body. Unfortunately, the only facts that we are in possession of by which this question can be determined, are, the termination of life generally, and the certainty that in old age the accumulation of useless elements in the tissues is constantly increasing, that the quantity of animal matter in the bones diminishes, and that calcareous matter is deposited in the coats of arteries and other parts. D'Outrepont[*] supposes that life itself is attended with, and is the mere result of a constant exchange of material in the fluids and organised solids. It has already been shown that life is attended with a constant decomposition of the material of the body. Every action produces a change in the composition of the active part, and excites a call for the restoration of the natural composition, which is gradually effected during the state of rest. It appears, therefore, really that even the organised solids undergo a gradual decomposition of their component particles, which is inseparable from their state of action, and which itself induces renovation.

In the Prolegomena on General Physiology I have stated all that is known respecting the balance which subsists between the destruction of material produced by the state of action and the succeeding renovation; but, unfortunately, such delicate relations cannot be subjected to calculation. We have here only very imperfect data, such as the fatigue after action, and the necessity for a large quantity of stronger nourishment after great mental or muscular exertion; while, on the other hand, the permanence of certain colouring matters introduced into the skin, points out a limit to the process of absorption and renovation. Within these limits, too, the indications of the renewal of the substance of the organised solids are of very various degrees of distinctness: we may instance, for example, the frequently quick disappearance of warts from the skin; the rapid absorption of bones, and their rapid union after fracture; further, the very gradual reduction of a shapeless callus to a form corresponding more nearly to the natural outline of the bone, during which process the cavity of the bone is restored at the point of fracture, sometimes after the expiration of months; while the difficulty with which specks of the cornea are removed, shows us how the inactivity of the renovating process here corresponds to the paucity of blood-vessels.

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[*] Diss. de perpetuâ materiei organico-animalis viciss. Hal. 1798. Reil's Archiv. iv. 460.

The exchange of material, lastly, is most considerable in youth, and diminishes more and more as age advances.

b. Chemical composition and form of the organised tissues.—The formation and development of these tissues has been already described, agreeably to the recent discoveries and views of Schleiden Schwann, Chap. I. Book I. Their chemical composition in addition to that given at p. 115, *et seq.*, will be more appropriately noticed when speaking of their functions.

c. Influence of the nerves on nutrition.—We are still much in the dark concerning the influence of the nerves on nutrition. Affections of the brain and spinal cord producing paralysis sometimes leave the nutritive functions quite unaffected. In many instances, on the other hand, the paralysed parts waste and lose their firmness; and, what is especially indicative of the influence of the nerves on nutrition, injuries of such parts are very liable to be followed by gangrene. Schroeder van der Kolk has observed that in some cases the muscular substance is converted into fat and the arteries are ossified.

In the embryo, the nutritive process is remarkably independent of the brain; for the nutrition of anencephalous monsters is by no means defective, and their development up to the period of birth is perfect. But, where any particular nerves have been deficient, the parts corresponding to them have likewise always been absent; and where any organ is wanting, there is always a corresponding absence of the nerves. Tiedemann (*Zeitschrift f. Physiol.* i. 76,) has in three cases observed absence of the olfactory nerves coincident with an imperforate state of the cribriform plate of the ethmoid bone and cleft palate. Absence of the eyes is attended with absence of their nerves. Mayer (*Tiedemann's Zeitschrift.* ii. 41,) has described a monster in which the lower extremities were present, with the exception of the absence of two toes on the left foot, but in which the urinary apparatus was absent and the generative organs were imperfect; and here the cauda equina was also very imperfectly developed, ceasing abruptly opposite the twelfth dorsal vertebra, while the nerves of the lower extremities were present. In several imperfectly developed monsters the nerves have been said to be wholly wanting; but this assertion may with tolerable certainty be attributed to the difficulty and inaccuracy of the examination. In acephalous monsters which consisted of one extremity merely, a ganglionic nervous mass has been found, from which the nerves of the extremity arose, and which must be regarded as the rudiment of a spinal cord.

The reciprocal dependence of the organs and nerves on each other may be observed very clearly in the metamorphoses of insects, and of the amphibia. Thus, in insects during the metamorphosis, the nervous system undergoes a change of form which has an exact relation to the organs of the creature in its future state; in the caterpillar the ganglia of the nervous cord are nearly uniform, corresponding with the segments of the body; but during the metamorphosis, when individual parts of the body are more developed, and the legs and wings are formed, several ganglia become united into larger masses, opposite the points where the new organs are developed.*

During the transformation of the larva of the frog, the tail disappears, and with it the extremity of the spinal cord, while simultaneously with the appearance of the extremities their nerves are developed.

This reciprocal dependence of the organs, and of the nerves, on each other for their existence, must not induce the belief that the production of the organs depends on the pre-existence of the nerves. This is by no means the case; both organs and nerves are produced by the same power, the *nisus formativus*, which resides undivided in the germ. When once the organs are formed, however, their constant renovation seems really to depend in part on the influence of the nerves. Several species of animals, even in their fully developed state, reproduce parts which are lost. The extremities, gills, lower jaw, or eyes, may be removed from the larva of the salamander, and will be reproduced. In this case it is uncertain whether the vital organising principle which exists in all parts of the animal regenerates these parts, in the same way as in the first development of them; or whether the central parts of the nervous system which are uninjured by the lesion, effect the reproduction of the parts to which they send nerves. The reproduction of an extremity in the salamander is said to be prevented by its nerve being divided at a second point above the surface of the stump.(?) In the former edition of this work the translator related, with Dr. Sharpey's permission, the following experiment on a salamander:—A considerable portion of the spinal cord at the root of the tail was carefully removed, together with the arches of the vertebræ, and the tip of the tail was then cut off; the tail was, of course, quite paralysed; but reproduction here went on as rapidly as in other cases in which the spinal cord was not injured above the wound, and at the end of six weeks the newly formed portion of tail was at least one-fourth of an inch in length. As in this experiment, however, the influence of the brain only was cut off, the spinal cord being left in the tail, the translator has repeated it in a different manner. Instead of removing a portion of the cord only at the root of the tail, he has cut off the end of the tail, and then thrust a thin wire some distance up the spinal canal so as to destroy the cord to the same extent. In one instance the wire was passed so far up that the posterior extremities were paralysed as well as the tail. The result was in all cases the same. Reproduction of the end of the tail took place, but much less rapidly than in salamanders in which the spinal cord had not been destroyed. Thus, in a large salamander, in which, after the end of the tail had been removed, a wire was thrust half an inch up the spinal canal, and moved about in it so as to destroy the cord, there is, after the lapse of nine weeks, a new portion of tail produced scarcely more than ⅛th of an inch in length; while in another salamander of the same size, and placed under the same circumstances, but in which the spinal cord was left uninjured above the point of amputation of the tail, the new portion of tail is ½ an inch in length. This result corresponds with what we see to be the most usual effects of paralysis in the limbs of the human subject, namely, diminution, though not arrest of nutrition.

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* Herold, Entwickelungs-geschichte des Schmetterlings. Cassel. 1816.

It might be urged, as an argument against the nerves exerting an influence in nutrition, that bones are reproduced although they have no nerves; but the nutritious vessels of the bone may, like other parts, be supplied with minute branches from the sympathetic system.

There are few experiments on record calculated to determine in a direct manner the influence of the nerves on the action of the small vessels. Magendie (*Journ. d. Physiol.* iv. 176, 304,) observed that emetics injected into the veins produced inflammation of the lungs and stomach, but that these effects were much less in degree when the nervi vagi had been previously divided. Magendie remarked likewise that, after division of the fifth nerve, strong stimulants excited no inflammation in the eye; but that after a few days, inflammation, with exudation into the interior of the globe, came on even when no irritants had been applied. Dupuy has seen inflammation of the eye ensue after removal of the superior cervical ganglion of the sympathetic, and Mayer has remarked the same occurrence after tying the sympathetic nerve. (*Gräfe u. Walther's Journ.* x. 3.) Dr. J. Reid, also, has seen the effect produced in dogs by division of the sympathetic nerve and vagus in the neck. (*Edin. Med. and Surg. Journ.* July, 1839.) Schroeder (*Observ. Anat. Pathol.* 1826, 14,) performed the following experiment:—He divided the ischiadic and crural nerves of one leg in a dog, and made a wound in both feet. On the following day the wound of the paralysed limb was dryer than that of the sound limb; during three weeks the wound of the sound foot presented violent phenomena of inflammation,—suppuration and granulation took place in it; while in the wound of the paralysed foot there was scarcely any inflammation; it discharged a white matter which formed a crust; but the wound itself was pale.

I have only once among several cases in which I divided the ischiadic nerve in rabbits for the purpose of investigating the reproduction of nerves, observed that the skin of the heel of the paralysed limb gave way and ulcerated at the part on which the animal rested.

To the influence of the nervous system on the action of the capillaries may also be referred the sudden change observed in the condition of wounds after violent affections of the mind. Vering and Langenbeck (*Schroeder van der Kolk, l. c.* p. 28,) have remarked that wounds under such circumstances, often suddenly lose their favourable aspect. The increased heat and redness, and tumefaction frequently observed in parts affected with a paroxysm of neuralgia,* seem to prove the influence of the nerves on the nutritive processes.

There is no proof that the sympathetic nerve has a more especial influence on nutrition than the cerebro-spinal nerves, except, perhaps, the fact that the nutrition of a part does not cease when the nerves which it receives from the brain or spinal cord are divided.

CHAPTER II.

OF GROWTH.

The growth of the solid textures of organised beings is effected in two ways. It may either be interstitial, each of the small particles of the tissue contained in the meshes of the capillary network being enlarged, while the number of vessels is at the same time increased, which is the mode of growth of vascular parts; or it may be effected by the apposition of layers of new matter secreted by a vascular matrix, the parts, which acquire increase of bulk in this manner, themselves having no vessels.

A very important law regulating the formation and growth of all organised textures has recently been brought to light, by the labours of Schleiden and Schwann. It is found that in the production of any given form of tissue, such as a fibre or tube, nature does not at once unite the organic molecules in that form, but that she first creates by a definite process round vesicles or cells, and subsequently transforms these into the various elements of the organic textures.

The predominance of the cellular form of tissue in the vegetable kingdom had been long known, and the correctness of the opinion that all varieties of vegetable tissue were really modifications of one type, the cell, had been demonstrated by M. Mirbel.† It had also been observed, that several structures in animals bear a great resemblance to the cellular tissue of plants,—a resemblance, indeed, amounting to identity of form in some instances; for example, in the branchiæ in the tadpole, the development of the internal branchiæ which continue to exist during the greater part of the larva state, the disappearance of the tail, and the final loss of the branchiæ, have been already mentioned. The generative organs are not developed till near the termination of the larva condition. I could not discover any trace of the testes and ovaries before the transformation into the perfect state had commenced, when the animal had already four extremities, although it still retained the tail and branchiæ. Even in the salamanders, which have extremities during the greater part of their larva state, the genitals are not developed till near the termination of this condition, just before the branchiæ are lost. The intestinal canal of the frog in the larva state was destined for vegetable food, and was consequently of extraordinary development; during the metamorphosis it is reduced to the condition of the canal in carnivorous animals. The vertebræ, also, which in the larva state were connected by excavated facets, as in fishes, undergo change at the same period.

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* See Swann, on Local Affections of the Nerves. London, 1820, p. 43; and Brodie, on Local Nervous Affections.

† Annales du Musée, 1831 and 1832; and Lindley's Botany, 3d edit. p. 8.

The metamorphoses which animals undergo during the processes of development and growth depend partly on the development and reduction of similar parts.

It has been said that the embryo, during its development, passes through stages of transition which are permanent conditions of lower animals; and this hypothesis, incorrect in itself, has been extended to an extravagant length. Nevertheless, in it there may be perceived some prevision of the real law, which escaped the observation of those who opposed it. Von Baer has the merit of having first discovered the real relation which the phenomena bear to each other; he pointed out, that in the Vertebrata, from man down to fishes, there is one common type of formation, a certain sum of similar organs, which in the embryo state of all are met with in perfect similarity, but which, during their development, assume different forms in different classes of animals, or are even reduced to a state lower than the original type; thus, for instance, in the embryo state of all the Vertebrata the os hyoides has rib-like appendages, but in the higher classes these are partly lost, while in fishes, and the larvæ of the Amphibia, they are developed to form the branchiæ.

All the *Vertebrata* resemble each other in presenting a series of vertebrate bones with arches posteriorly to protect the central parts of the nervous system, and a number of anterior appendages, in the form of ribs, to enclose the viscera. A part of these anterior appendages meet cartilaginous or osseous ribs connected with the sternum, so as to form a thorax; while the ribs belonging to the cervical and lumbar vertebræ are absent in many of the Vertebrata, and in others (the Crocodilida and Lacertæ) the appendages of the cervical vertebræ are merely rudimentary. In all the Vertebrata, the vertebral system here indicated dwindles away to an imperfect condition at its lower part under the form of the coccygeal vertebræ, and is more highly developed superiorly in the three vertebræ of the cranium. More than three vertebræ I cannot discover in the cranium; to mark out vertebræ in the ear, &c. seems to me to be an exaggeration and an abuse of an analogy which is, to a certain extent, quite correct. In all embryos of the Vertebrata the extremities are at first absent; their first form in all is that of small prominences, which afterwards take different forms in the different classes. Thus we see how the forms of the developed vertebrate animals depend on the transformations and reductions of one common type. Some animals during growth deviate more, others less from the form which this type presents in the embryo and larva state.

In the *articulate classes*, in which the brain, it is true, lies above the œsophagus, but in which the nervous cord, that forms its continuation through the intervention of a ring which surrounds the œsophagus, runs along the abdominal surface of the body, a common type peculiar to them is again evident, consisting of a series of rings enclosing the body, and connected with each other in a series from before backwards. The maxillæ and mandibles appear, from Savigny's researches, to belong to the same system of organs with the feet.

The *insect*, while in the larva or caterpillar condition, has thirteen rings or segments of the body; it is only during this state that it increases in size, changing its skin three or four times: by the metamorphosis which it undergoes during the pupa or chrysalis condition, it is converted into a new creature. Before the organising power which produces this change of form can be exerted, it is necessary that the uniform members of the larva shall have attained a certain size. The continued nutrition of the parts of the larva by the introduction of food, seems to delay the production of the metamorphosis, for insects undergo transformation earlier when no food is given them, just as plants blossom earlier in poor soil; but in proportion as the parts of the larva, as yet uniform, increase in size, the stronger seems to become the tendency to the production of differences of form, by the reduction of some parts and the development of others.

When the last change of the skin takes place, the insect, enveloped in its cocoon, assumes the chrysalis form; the external tegument of which, like all horny matter, is at first soft. In the external form of many pupæ the rudiments of the exterior figure of the future insect may be already traced, the extremities being pressed closely to the body. The fundamental features of the change in the external form of the insect are displayed in the transformation of the larva to the pupa. The division of the future animal into three parts is already seen; the three rings of the body which follow the first, or cephalic ring, being converted into the thorax, in which the protothorax, mesothorax, and metathorax are afterwards recognised, while the posterior nine of the thirteen segments become shortened, and form the nine rings of the abdomen of the perfect insect; the rudiments of the wings are formed on the second and third ring of the thorax; the antennæ and palpi on the head or cephalic ring. The organs for the perception of light do not exist in many insects until they undergo transformation; in others compound eyes are then developed in the place of the simple eyes of the larva. Of the thirteen ganglia of the nervous cord in the larva of the cabbage moth,—Papilio brassicæ,—the third becomes united with the fourth, and the fifth with the sixth, while the seventh and eighth wholly disappear. The viscera undergo corresponding changes. The butterfly acquires a proboscis in place of the maxillæ of the caterpillar; its vessels for the secretion of the web disappear. The intestinal canal and respiratory organs are changed in form. From the commencement of the metamorphosis the fatty body is rendered almost fluid; it is chiefly employed in the formation of new organs. We have seen that in the larva of Amphibia the generative organs are at first absent, but Herold has found that, in insects, extremely delicate rudiments of the testes and ovaries exist even in very young larvæ. Many insects retain the larva type.*

With regard to the *Crustacea*, it is observed, not only that the higher genera in their embryo state have a thorax composed of distinct segments, and thus resemble the permanent condition of the lower genera, but that the Crustacea, when young, are frequently much more simple than afterwards,—for example, the young Cyclops has but two antennæ and two pairs of feet. Some Crustacea, indeed, undergo a perfect metamorphosis; this is the case with the Lernæa tribe. The proper place in the scale of animals for these strange, parasitic creatures was long doubtful, because when fully formed they had lost almost all traces of their former division into segments; hence many naturalists classed them improperly with the Entozoa. Nordmann (*Microgr. Beiträge.* ii.) has discovered that in the embryo and larva states these animals have the form of perfect Crustacea. The embryo of the achteres percarum has, for instance, four pencil-like feet. After it has left the ovum, it has two antennæ, three pairs of anterior cheliform feet, and two pairs of flabelliform feet, and is similar to the fish-louse (Caligus). The young of the genus Ancorella, even while in the ovum, have a red eye.

During the growth of the *Annelida* the number of their rings increases, and in the Arenicola the number of the tufted branchiæ also; at least I am induced to think so on comparing different specimens of the Arenicola carbonaria.

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* For further information on the metamorphoses of insects, consult the classical work of Herold, Entwickelungsgeschichte der Schmetterlinge. Cassel, 1815.

BOOK IV.

PHYSIOLOGY OF THE NERVES.

SECTION I.

Of the Properties of the Nerves generally.

CHAPTER I.

OF THE STRUCTURE OF THE NERVES.

*a. Of the principal forms of the Nervous System.**

The first great distinction to be made in considering the forms of the nervous system in the animal kingdom, is between that of the Vertebrata, in which the brain is not pierced by the œsophagus, and is prolonged into a spinal cord, and that of the Invertebrata, in which the brain is always represented by a nervous ring through which the œsophagus passes. This nervous ring of the Invertebrata presents, on the dorsal aspect of the œsophagus, a large ganglion, or brain; while there is likewise another enlargement or ganglion occupying the lower part of the ring, and situated below the œsophagus, from which the rest of the nervous system, whether it consists of single nerves, or of a cord with a series of ganglionic enlargements, as in the Annelida, Crustacea, Insecta, and Arachnida, takes its origin.

The relation in which the nervous system of invertebrate animals stands to that of the Vertebrata is a problem which has long occupied the minds of anatomists and physiologists. Ackermann, Reil, and Bichât compared the ganglionic system of Invertebrata with the sympathetic nerve of the higher animals; and the same proposition has very recently been started anew by Serres and Desmoulins. Scarpa, Blumenbach, Cuvier, Gall, and J. F. Meckel have, however, on better grounds, denied the existence of such an analogy; and the greater number of these anatomists have regarded the abdominal cord of the Articulata simply as the analogue of the spinal cord of the Vertebrata. According to the view of Meckel and Ph. v. Walther, that part of the nervous system of the Invertebrata which is continued from the brain into the trunk of the body, includes both the spinal cord and sympathetic system of the higher animals; and, while it has in all cases the function of the two, it in the Mollusca approaches more nearly to the type of the sympathetic, in the Articulata to that of the spinal cord. Treviranus and E. H.

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* See a more extended view, by J. Müller, in the Nova Acta Nat. Cur. t. xiv. and in Meckel's Archiv. 1828.

Weber, lastly, imagined that the ganglia of the abdominal cord of the Articulata must be looked upon as nothing more than the ganglia of the spinal nerves which have coalesced; the intermediate cords being merely the first rudiments of the medulla spinalis. The question has been at length decided by the discovery that in most articulate animals, and in all insects, there is, besides the abdominal cord, a second system of nerves destined solely for the viscera, which likewise consists of a series of delicate ganglia more minute than those of the abdominal cord, attains its greatest development in the formation of plexuses on the intestinal canal, and particularly on the stomach, and is connected by radicle fibres with the brain. Traces of a nervous system exist, according to Ehrenberg, even in the Infusoria; at all events, he has seen them in the Rotifera.

Among the best known forms of the nervous system, in the lower animals, the three following types may be distinguished.

1. *Type of the Radiata.*

Similar members arranged around one centre.—The primitive form of the nervous system is the ring, which in the Invertebrata generally is known as the œsophageal ring. Its simplest form is met with in the Radiata, in which the ring is still without ganglionic enlargements, or a cord-like prolongation. The distribution of its branches corresponds with the radiate division and structure of the animal. There being no prolongation of the body of the creature into an articulated trunk, there is likewise no nervous cord developed as a prolongation of the œsophageal ring. The repetition of similar organs in the periphery of a circle is the character of the type according to which the animal is here formed, and hence all the nerves given off from the œsophageal ring are similar; no one is especially the prolongation of the ring, and no one part of the ring has especially the function of the brain. All the radiating branches of a nervous circle, of which no one has a greater importance than the rest, constitute together what in the higher animals is represented by the principal nervous cord.

2. *Type of the Mollusca.*

No division into members, the viscera enclosed in a common muscular sac.—In molluscous animals the primitive form of the nervous system undergoes changes which only correspond to the modifications that have affected the whole organism. The symmetry of the radiate type is lost; and, as one most essential character, there is a want of the articulate structure of the other Invertebrata. The molluscous animal consists merely of a convoluted mass of viscera in sufficient number to constitute an individual animal organism, of which the proper animal or sensitive functions seldom exceed an awkward touch and a sluggish locomotion.

The fundamental œsophageal ring is present here also; but, there being no radiate divisions of the body, the nervous ring does not give off radiating branches. There are nerves of sense, nerves for the viscera, and nerves for the muscles; the viscera not being arranged with any symmetry or order of succession, and there being no regular series of locomotive members, there is not required in the nervous system any succession of similar parts.

The sole development which the nervous system in this type undergoes, consists in ganglia being formed on the œsophageal ring and its nerves, as centres from which branches are given off. The grades which this development is observed to pass through are the following:—

1. Ganglia on the œsophageal ring at its superior and inferior parts, (supra-œsophageal and infra-œsophageal ganglia,) as in the Gasteropoda; or lateral ganglia on the œsophageal ring, and on the nerves arising from the ganglia of the ring, as in Acephala.
2. The œsophageal ring developed into a large cerebral mass, as in Cephalopoda.

3. *Type of the Articulata.*

The body divided into a series of similar or identical parts, the contents of all of which are either similar or identical.—The fundamental character of the articulate animals is, that the body is formed of a succession of rings either similar or identical, which again contain either similar or identical parts of the vascular system and viscera. The organs are no longer included in a convoluted mass by a muscular sac; but are extended for the most part in one direction, namely, longitudinally; and the muscular sac has become divided into a number of separate muscles for the different segments of the body. To correspond with this structure, the œsophageal ring and its ganglia are repeated in the form of the gangliated nervous cord.

This is the case in Annelida, Insecta, Arachnida, and Crustacea. The brain in all the species of these classes seems to be, without exception, above the œsophagus.* In insects the special nervous system of the viscera becomes distinctly developed.

The union of several of the ganglia of the abdominal cord, the disappearance of some, and the fusion of others into larger masses during the metamorphoses of insects, in accordance with the necessities of the parts which have become more highly developed, are now well ascertained. In some few insects all the ganglia and loops of the double abdominal cord are united into one solid column from which all the nerves of the articulated body radiate, but this column is connected with the cerebral ganglion by means of the œsophageal ring, which remains open. Such is the structure in the Scarabæus nasicornis even in the larva state. Here then the gangliated cord is converted into a simple cord, and thus the brain and spinal marrow of vertebrate animals would seem in fact to differ in form but little from the nervous system of Invertebrata. There remains as peculiar to the latter animals only the passage of the œsophagus through the nervous ring. On the other hand, we see that in the lower Vertebrata, the ganglionated structure is again met with in the spinal cord at the points where large nerves arise from it: thus there are several ganglionic enlargements of the cord in the cervical region in the flying fishes (Triglæ), and there are enlargements of the spinal cord in Chelonia, birds, and Mammalia at the points corresponding to the origin of the nerves of the upper and lower extremities.

There are no grounds for comparing the nervous system of molluscous animals to the sympathetic nerves of the Vertebrata. The absence of the chain of ganglia in the former animals is the consequence of their body not consisting of a series of segments. The union of the ganglia in a series is an accidental circumstance, which has its origin not essentially in the nervous system itself, but in the general structure of the body. Hence, even in the articulate classes, when the division of the body into segments is absent or subordinate, the chain of glanglia is replaced by ganglia situated on the different nerves arising from the brain, as in Mollusca; such, for example, is the case in the Phalangita. The ganglia of the Mollusca belong therefore in part to the nerves of the viscera, and are destined for the organic functions; while those cerebral nerves, and their ganglia, which are distributed to the organs of motion, as the mantle (in the Sepia), and are capable of exciting voluntary motions, are wholly analogous to the muscular nerves arising from the gangliated cords of the Articulata, and are quite distinct from visceral nerves. Other views respecting the functions of the different parts of the nervous system of invertebrate animals have been suggested by Dr. M. Hall's hypothesis of the existence of distinct nerves for the reflex movements, in addition to the nerves of volition and sensation. The consideration of these views is reserved to the Chapter on the Motions produced by Reflex Nervous Action, to their connection with which subject they owe their chief interest.

b. Of the minute structure of the Nervous Substance.

Primitive nervous fibres.—The nerves are constituted of parallel fasciculi of different sizes, invested with a membranous neurilema.

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* In the Scorpion, as in other Articulata, the œsophagus passes through the œsophageal ring; but the posterior or inferior enlargement of the ring is larger than the anterior, which circumstance it was which formerly misled me to the belief that here the brain lay below the œsophagus. In the Phasmæ also the brain is placed as in all insects, though in 1826 I thought differently.

These fasciculi, examined along the course of a nervous cord, are found to be connected with each other at intervals; but the parallel primitive fibres contained in these fasciculi run merely in apposition with each other; they do not unite: even where the fasciculi appear to anastomose, there is no union of fibres, but only an interchange of fibres between the fasciculi.

The primitive fibres of the nerves are very similar in form and size in different animals; they are in all cases simple threads, and are never formed of globules. In the human subject their diameter is, according to Krause, from $\frac{1}{378}$ to $\frac{1}{184}$ of an English line; and according to Prof. R. Wagner, $\frac{1}{377}$: in the frog, the last observer states them to measure $\frac{1}{184}$ of a line in diameter. They vary, however, very much in size, and are frequently, especially the grey fibres, much more minute than the above measurements indicate. The capillary blood-vessels exceed the nervous fibres in size, and consequently do not ramify upon them, but merely form a network which occupies their interstices. Fontana appears to have been the first who had a correct idea of the structure of the primitive fibres. He distinguished in them an external tubular portion, which, when highly magnified, had a wrinkled aspect, and a solid internal portion, which formed a smooth homogeneous thread. He was able to separate the tubular sheath from its solid contents in some fibres.

These observations of Fontana are quite in accordance with those recently made by Remak, who first directed attention to the paragraph in the work of Fontana. But both Valentin (*Repertorium*, 1838, p. 76,) and Henle (*Müller's Archiv.* 1839, p. 174,) regard Remak as incorrect in describing the contents of the nervous cylinder to be solid. In the fresh state, when no reagent had acted on the nerves, they found the fibres to contain a perfectly transparent and fluid matter, which the addition of water, however, caused to coagulate. The flattened pale filet which remains after a nervous fibre has been subjected to pressure, and which Remak supposed to be the solid fibre freed from the investing tube, appeared to Henle to be the tube itself emptied of its contents.

The great size of the so-named primitive fibres of the nerves, as compared with the minute elementary parts of muscles, and of the cellular and other tissues, excites a doubt as to whether the fibre contained in the nervous cylinder is really its most minute element. In fibres of the thickness of the ordinary primitive nervous fibres, which Schwann examined in the mesentery of the frog, he saw other much finer filaments, which issued from the larger fibre. Treviranus observed in several nervous cylinders streaks running longitudinally, and he even saw distinctly more minute elementary filaments in the so-called primitive cylinders.

Fibres of the cerebral substance.—The fibres of the brain were known to Fontana. He describes them as being cylinders filled with a gelatiniform fluid, but his notion of the intestine-like convolutions of these tubes is quite incorrect. He attributed too much importance to the curved disposition of the fibres, which is an accidental state produced in the preparation of the nervous substance for microscopic examination; for the primitive fibres of the brain and spinal cord have for the most part a tolerably straight direction. Ehrenberg, however, has described the tubular structure of the cerebral fibres, and their arrangement in the brain and spinal cord, very accurately. He states that they run generally in straight lines, and do not anastomose. He very rarely saw them divide; for example, in a few instances in the spinal cord. The division of the fibres may, however, be frequent even in the brain, since the mass which the diverging fibres constitute evidently increases between the medulla oblongata and their radiated expansion in the grey matter of the outer part of the optic thalamus. Ehrenberg* has discovered that the primitive fibres or tubes of the brain and spinal cord and those of the optic, olfactory and auditory nerves, assume on the slightest pressure a beaded appearance, or are varicose. Treviranus, however, has shown that the primitive fibres in all parts, in the brain as well as in the nerves, are for the most part straight, and not varicose. The observations of Lauth and Remak also tended to show that an arrangement of the nerves according to the cylindrical or varicose form of their primitive fibres is scarcely possible, since single varicose fibres are met with more or less frequently in the most different nerves. The same fibre sometimes presented the cylindrical and the varicose form alternately at intervals, and the fibres of the nerves generally in young animals are prone to exhibit this appearance.

It is, however, a characteristic property of the fibres of the brain, and the nerves of special sense, that they are exceedingly prone to become varicose. No other tissue has this property; and, in enumerating the characters of the cerebral fibres, it cannot be omitted. It is not quite certain on what this property depends.

White and grey fasciculi in the nerves.—It is well known that the fasciculi of nervous fibres in the symphathetic nerves have for the most part a grey aspect, while those of the cerebro-spinal nerves are white. But the latter nerves also contain some few grey fasciculi mingled with the white; and, in many parts of the sympathetic nerve, there are white fibres mingled with the proper grey, or organic fibres. (The microscopic and other characters of these organic nervous fibres will be given in Section ii. Chapter 4.)

The structure of the anterior motor, and that of the posterior sensitive roots of the spinal nerves, have been made the subject of comparative examination by Ehrenberg together with myself, and we detected no difference between them.

Course of the fibres and their arrangement in the nerves.—A knowledge of the course of the primitive fibres in the nerves is of the utmost importance: for, although an exact acquaintance with the ramifications of the nerves is indispensable, yet, in the study of the actions and properties of the nervous system, we must at last come to the question, Where do the primitive fibres contained in a nervous fasciculus arise, and where do they terminate? It is, at least with reference to many questions concerning the functions of the nerves, a matter of indifference into what fasciculus the fibres enter, or how soon they issue from it; since, as will presently be seen, they themselves (the primitive fibres) remain distinct and isolated throughout their course; and this is the first and most important point to be decided. If the primitive fibres never anastomose, it must follow that the cerebral extremity of each fibre is connected with the peripheral extremity of a single nervous fibre only, and that this peripheral extremity is in relation with only one point of the brain or spinal cord; so that, corresponding to the many millions of primitive fibres which are given off to peripheral parts of the body, there are the same number of peripheral points of the body represented in the brain. If, on the contrary, the primitive fibres anastomose with each other in their course within the small fasciculi, and in the frequent anastomoses and plexuses of the nerves themselves, and do not merely lie in apposition; then the cerebral extremity of a nervous fibril will be in relation with very many peripheral points, the number of which will be equal to the number of primitive fibres which have coalesced. Now, since the nerves are seen to anastomose in all parts of the body, there would, if the primitive fibres likewise anastomosed in these situations, be scarcely a single point of the body represented isolated and distinct in the brain; the irritation of a primitive fibre in a single point of the skin would necessarily be propagated through all the anastomoses,—in other words, no local impression on a single definite point would be perceived by the brain; for the sensation of a single point evidently depends on the impression being conveyed by means of a single fibre to a single point of the sensorium. It is very clear, that if the anastomoses of the nerves in the transmission of the nervous principle had the same influence as the anastomoses of vessels, no local nervous influence could be communicated from the brain to the peripheral parts, or from the latter to the brain. The possibility of our establishing an accurate theory of the action of the nerves consequently rests wholly on the question, whether or not the primitive nervous fibres anastomose.*

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* Poggendorf's Annal. xxviii. Hft. 3.—Abhandl. d. K. Akad. zu Berlin aus d. J. 1834. Berlin, 1836, p. 605.

Fontana, and afterwards Prevost and Dumas, observed, that the primitive fibres of nerves enclosed in a fasciculus do not unite with each other, but merely run side by side. At that period, however, physiologists had scarcely a suspicion of the importance of this fact in relation to the theory of nervous action. I have examined with the simple microscope the primitive fibres of a nervous fasciculus spread out on a black surface, but have never seen two fibres unite into one: they always were seen to continue separate, whether they lay side by side, or crossed the one over the other; and, even where two fasciculi have united, I could perceive no actual union of fibres,—these remained evidently quite distinct, and were merely in juxtaposition. When nerves form a plexus, the nerves which issue from it, however great the interlacement of fibres may have been, will always form as large a mass as those that entered it. The same law prevails in the ramification of nerves: a nerve, after having given off a branch, is thinner in exact proportion to the number of fibres in the branch which has left it; and by the aid of minute dissection it is easily seen that, when a branch is given off, the fibres in the trunk do not divide each into two, one remaining in the trunk, while the other leaves it to join the branch, but that the fibres of the branch are some of those which already existed in the trunk: hence, in a nerve, very different fibres, sensitive and motor, may be associated together, and in the trunk of a nerve there may even be branches contained which do not unite with the other constituent fasciculi, and have no resemblance to them in its properties. Thus the nervus mylohyoideus, a motor nerve, is commonly regarded in a general way as a branch of the inferior dental, a nerve of sensation, although these two nerves have nothing in common except their position side by side; and of this there are frequent examples. We hence see that the properties of the component fasciculi have nothing to do with the nature of the trunk of the nerve itself; but that, on the contrary, the nervous trunk, particularly at some distance from the brain, may be constituted of fasciculi of very various properties, the different fasciculi destined for a particular limb having become annexed to it in its course.

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* Similar arguments in favour of the insulated course of the nervous filaments were advanced by Dr. Whytt. (See Whytt's works, p. 505.)

The view here given of the course of the primitive nervous fibres from the brain to their ultimate termination, is opposed to the statement that the nerves increase in size in their course, which, however, is an error originated by Soemmering. The nerve is certainly smaller before it passes through the dura mater, and receives its neurilema, than it is afterwards; but, when invested by its neurilema, its diameter does not vary as long as it gives off no branches. The branches in every case contain the same mass of nervous substance as the trunk from which they arise; if there is a slight difference, it is owing to the quantity of neurilema in the branches being greater. These remarks on the ramification of nerves, apply also in the case of a plexus formed by two different nerves. Some years ago I examined, with the most careful dissection, the anastomoses of the facial with the infra-orbital nerve in the rabbit and sheep; and convinced myself, by accurate drawing of the course of the primitive fibres of both, that the fibres merely apply themselves to one another, and arrange themselves into new fasciculi. With these principles, therefore, we must regard the primitive fibres of all the cerebro-spinal nerves as isolated and distinct from their origin to their termination, and as radii issuing from the axis of the nervous system. Strictly considered, these radii issue from the spinal cord in a nearly continuous line on each side; but a certain number of them are collected at intervals into a fasciculus for the convenience of their distribution to the peripheral parts.

The foregoing results of my own observation I have taught for several years in my lectures. In the year 1830 I had an opportunity to communicate them in conversation to Prof. Van der Kolk, of

Utrecht, when I begged him to put my observations to the test. The views which I had adopted, and which agree with those of Fontana and Prevost, have recently received confirmation in my mind from my illustrious colleague, M. Ehrenberg, having verified the observations on which they rest. The subject has been treated very fully by Kronenberg. (*Plexuum Nervorum structura et virtutes. Berol.* 1836.)

The above statements refer merely to the white fibres of the cerebro-spinal and sympathetic nerves; for it is probable that the grey fibres may be connected with each other (at all events, through the medium of the ganglia.)

Mode of termination of the nerves.—This is a subject, the investigation of which has occupied Treviranus, Gottsche, Valentin, Emmert, the younger Burdach, and Schwann. The question of chief interest was, whether the nervous fibres terminate by uniting with each other, or remain isolated even at their extremities. Microscopic examination has shown that the nervous fibres terminate in three ways; namely, by the formation of regular anastomosing loops between every two fibres; by uniting so as to form a network like blood-vessels; and thirdly, by free isolated extremities.

In the retina, and in the ear, the nervous fibres terminate in an isolated manner, without uniting with each other.

Treviranus observed the papillar mode of termination of the nervous fibres, not merely in the retina, but also in the case of the auditory and olfactory nerves; and here the papillæ were more thread-like. Those of the auditory nerve he saw on the lamina spiralis of the cochlea in young mice. The bony portion was wholly covered with thread-like papillæ crowded closely together.

Termination of fibres of the brain.—The mode of termination of the fibres of the brain has been investigated by Valentin. The primitive fibres of the spinal nerves do not end in the spinal cord; they continue their course as far as the brain. The fibres of the nerves at the extremity of the spinal cord run at once in the longitudinal direction upwards, while those nerves which enter the spinal cord laterally at its upper part pass first transversely towards the interior of the cord, as far, or nearly as far, as the grey substance, and then follow the same longitudinal course to the brain as the others. In the white substance, the fibres lie in contact with each other; but, at the line of contact of the white and grey substances, they become separated by the globules of grey matter, which we shall presently describe, and at length radiate out into the cortical substance, where they form loops by uniting one with another. This is seen most distinctly where the white and reddish grey substances pass the one into the other, or in the yellow substance at the periphery of the hemispheres of the cerebrum and cerebellum.

Grey substance of the brain, spinal cord, and ganglia.—The elements of the ganglia of the nerves in the higher animals, and in the human subject, have been ascertained by Valentin to be globules of considerable size, which differ from the above-described club-shaped bodies merely by their more spherical form; but have like them a nucleus, and in the circumference of this another smaller nucleus, or nucleolus, and frequently also spots of pigment on their surface. One or more fasciculi of fibres which enter the ganglion form within it a plexus, the fibres assuming a different arrangement, and then issue from it again; while single fibres, or fasciculi of fibres, form an interlacement around the globules of the ganglion. The fibres which form this interlacement come off from the trunk of the nerve, and join it again. This description applies to the ganglionic globules generally, as may be easily verified.

The grey substance of the brain and spinal cord is, according to Valentin, formed wholly of the same globules as the ganglia. The appearance of minute granules is produced by the disintegration of the original globules, which are very soft. The only circumstance in which the globules of the grey substance of the brain differ from those of the ganglia, is that the cellular tissue which invests the former is less firm. In the white substance of the brain there are, according to Valentin, no globules or granules; the appearance of granules in it being produced by the disintegration of the nervous fibres. On the quantity of the deposit of grey globules depends the degree in which certain parts of the brain differ in colour from the white or fibrous substance: where the primitive fibres are in greatest number, the colour is whitish grey; where they are less abundant, it is reddish grey: the still darker colour of certain portions of the brain depends on the presence of a pigment deposited on the globules.

In the spinal cord there are, as Rolando discovered, two kinds of grey substance. That which is commonly known as the grey substance of the spinal cord, is called by Rolando[*] "*substantia cinerea, spongiosa, vasculosa.*" At the back part of the posterior cornua of the substance runs a line of perfectly grey matter, called by Rolando the "*substantia cinerea gelatinosa.*" The first contains, according to Remak, the great ganglionic globules above described, together with numerous fibres; the latter, on the contrary, contains corpuscules similar to the red particles of frog's blood. The continuation of the *substantia cinerea gelatinosa* in the medulla oblongata, where it comes to the surface, has the same structure.

Distribution of the white and grey systems of fibres in the cerebro-spinal and sympathetic nerves.—The mixed cerebral and spinal nerves contain chiefly fasciculi of sensitive and motor fibres, and a few fasciculi of grey fibres which have a tendency to the formation of ganglia; the sympathetic, on the contrary, contains a few sensorial and motor elements derived from the posterior and anterior roots of the mixed nerves, but consists chiefly of grey organic fibres, corresponding with its distribution to parts which serve principally for the production of chemical changes in the fluids of the body. Hence the frequency of ganglia in the sympathetic nerve; while in the cerebro-spinal system of nerves, if we except the regular ganglia of the posterior roots, ganglia are rare, occurring only where there is a considerable intermixture of grey fibres from the sympathetic.

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[*] Saggio sopra la vera struttura del Cervello; edit. 2. t. ii. Torino, 1828. Tab. iii. fig. 2, 3, sp.

Classification of the ganglia.—The ganglia of the nerves may be arranged in three classes:—

1. *Ganglia of the posterior roots of the spinal and cerebral nerves, the ganglion of the larger portion of the nervus trigeminus, that of the vagus, the ganglion jugulare superius of the glosso-pharyngeal nerve, and lastly the ganglion on the small posterior root of the hypoglossal nerve.*

These ganglia have the common character of belonging to nerves of sensation; we shall show at a future page that the posterior roots of the spinal nerves are sensitive, not motor. The ganglion of the first spinal nerve sometimes, and those of the last two always, present anomalies in respect to position. The first is sometimes situated within the cavity of the dura mater; (*Mayer. Nov. Act. Nat. Cur.* v. xxi.) the last two very delicate spinal nerves have their ganglia always in that situation. (*Schlemm, Müller's Archiv.* 1834, i.) The portio major nervi trigemini which expands into the Gasserian ganglion, bears the same relation to the portio minor as the posterior roots of the spinal nerves do to the anterior roots.

The structure of the ganglia of this class is not essentially different from that of the ganglia of the sympathetic; but we see in them more distinctly the pencil of fibres passing through unchanged between the globules of the proper substance of the ganglion. The special function of the ganglia of the sensitive roots is not yet known. Perhaps they give rise to the organic fibres of the sympathetic, which these ganglia would then connect with the posterior columns of the spinal marrow. The sensitive and motor white fibres of the sympathetic are connected with the posterior and anterior roots of the spinal nerves. The question, therefore, is, whether the posterior roots of the spinal nerves connect both the sensitive and organic fibres with the spinal marrow. The ganglia of the sympathetic itself, however, appear to be at all events a principal source of the organic fibres. The lateral cords of the sympathetic are proportionally much whiter than the branches of the great abdominal ganglia.

The facts which we have at present considered do not enable us to decide whether an increase in the number of fibres takes place in the ganglia of the sensitive roots, and in the Gasserian ganglion. It is certain that the white fibres pass through with merely a change of arrangement. But grey fibres may arise from the ganglionic globules, since it is indeed a known fact that grey fasciculi arise in the Gasserian ganglion, and accompany the branches of the nervus trigeminus. (See *Wutzer, de Gangliorum Fabricâ.* Berol. 1817.)

2. *Ganglia of the sympathetic nerve.*—It is so difficult a matter to ascertain what becomes of the nervous fibres in these ganglia, that we have, in fact, not the least knowledge on that point. The main question here, as in other parts of the nervous system, is, whether the primitive fibres really unite together, or merely lie in juxta-position, and form interlacements with others; or whether they divide in the peripheral direction, being thus multiplied. If a multiplication of fibres takes place in any ganglion, it is certainly most likely to be in those of the sympathetic; and it is, at least, very difficult to sup-

pose that all the primitive fibres of the abdominal plexus are contained in the roots which the sympathetic derives from the spinal nerves. But if this multiplication does take place, it can affect only the delicate grey organic fibres; for the ordinary primitive fibres of the nerves are known to pass unchanged through the ganglia of the sympathetic, as through those of the posterior roots of the spinal nerves.

The ganglia of the sympathetic form two series. The first consists of those which lie along each side of the spinal column at the points where the roots of the sympathetic nerve, coming from the spinal nerves, unite with the longitudinal cord of the sympathetic; it comprehends, therefore, all the cervical, intercostal, lumbar, and sacral ganglia. To the second series belong the sympathetic ganglia, situated in the middle line, or the plexiform ganglia in the plexuses of the abdomen.

3. *Ganglia of the cerebro-spinal nerves at the points where they are connected with branches of the sympathetic.*—These are the ganglion *petrosum nervi glosso-pharyngei*, the *intumescentia gangliiformis* on the angle of the facial nerve, the ganglion spheno-palatinum on the second branch of the nervus trigeminus, the ciliary ganglion, and perhaps, also, the otic ganglion, and some others. Ganglia are not always formed, however, where fibres of the sympathetic unite with fibres of the cerebro-spinal nerves; on the contrary, it happens very rarely; for at not one of all the numerous points of origin of the sympathetic from the cerebral and spinal nerves is there a ganglion formed. The reason why, in the instances above mentioned, the union of fibres of the sympathetic with cerebral nerves is attended with the formation of a ganglion on the latter, appears to me to be that, in these cases, branches of the cerebral nerves coming from the brain are not given off to the sympathetic, but that branches of the sympathetic here join the cerebral nerves; the fibres thus added to the nerves being continued then, not merely to the brain, but in the peripheral direction with the cerebral nerve. If this supposition were of general application, an enlargement on a cerebral nerve, not at its root, but in its further course, at a point where it was connected with a branch of the sympathetic, would always indicate that the fibres of the sympathetic were here not derived as roots from the cerebral nerve, but were fibres sent to the latter nerve from the sympathetic system. Thus in the ciliary ganglion there is a mingling of fibres of the nasal branch of the fifth nerve, of the branch of the third nerve to the inferior oblique muscle, and of the sympathetic; the object of which is not to give new roots to the sympathetic, but to bring into the ciliary nerves fibres of the sympathetic, with sensitive fibres of the first division of the fifth, and motor fibres of the third nerve.

Should the above view be confirmed, then the ganglia in question,—those just considered,—will no longer be a distinct class; but will belong to those of the sympathetic system, and will be included in the second class. The sympathetic system would in that case have three kinds of ganglia:

1. The ganglia of the middle line, or the plexus-like ganglia of the abdomen.
2. The ganglia of the lateral cords, lying at the points of junction of the roots of the sympathetic.
3. The ganglia of the sympathetic, which are situated at the points of junction of this nerve with the cerebral nerves, and which modify the properties of the latter, and not those of the sympathetic.

CHAPTER II.

ON THE EXCITABILITY OF THE NERVES.

The laws of animal excitability in general have been considered in the Prolegomena on General Physiology.

This property of organised bodies,—excitability,—is also possessed by the nerves, both the general and special endowments of which are in every instance manifested under the influence of stimuli. Physiologists have not however merely to ascertain the laws governing this general property, which, unfortunately, was the sole object that occupied the attention of Brown and his followers; but to investigate the peculiar forces themselves which are susceptible of this excitation, and in this there is a great field opened for experimental science. In inquiring into the nature of the forces resident in the nerves, it is necessary to study the action of all kinds of stimuli upon them,—a method of inquiry which acquires for physiology an experimental certainty similar to that which the science of physics and chemistry enjoy in reference to inorganic bodies. In chemical processes, reagents give rise only to products, combinations, and decompositions; applied to organic bodies, and especially to the nerves, their effects, how various soever they themselves may be, are never other than manifestations of the forces proper to the organic body or tissue acted on, and, subsequently, changes in these forces or properties; it will be seen that all influences acting on the nerves either excite them, or produce an altered state of their excitability; all stimuli, however different they may be from each other, act in the same manner; agents the most dissimilar produce the same effect, because that on which they act possesses but one kind of excitable force, and because they themselves act here by virtue of the same quality, that of stimuli.

1. *Of the Action of Stimuli on the Nerves.*

All stimuli, as well the internal organic as the inorganic,—the chemical, mechanical, caustic, and electro-galvanic,—when applied to parts endowed with sensation, or to sensitive nerves, the connection of the latter with the brain and spinal cord being uninjured, produce sensations. All these different stimuli resemble each other in this respect,—that a certain degree of their action produces merely the phenomena of sensation, while their more violent action induces changes in the force on which the sensibility depends. All stimuli, organic and inorganic, applied to the nerves of muscles, or to the muscles themselves, excite contraction of the latter; and this effect is produced, as well when the nerve is still in connection with the brain, as when its communication with the nervous centres is cut off. Nerves, therefore, have by virtue of their excitability the property of exciting contractions in muscles to which they are distributed; and this they do as long as the muscles preserve their vitality, and as long after death as they, themselves, retain their excitability. For the production of contractions in a muscle, by irritating its nerve, it is necessary that the latter shall not have lost its integrity between the point irritated and the muscle, although its connection with the brain or spinal marrow may not be preserved; while, on the other hand, all stimuli produce sensation in a nerve, whether it is entire or mutilated, as long as an uninterrupted communication subsists between the part irritated and the spinal cord or brain.

a. Mechanical stimuli.—Every kind of mechanical irritation,—stretching, compressing, or puncture,—excites in sensitive nerves, under the conditions already mentioned, sensations; provided the mechanical influence,—for instance, the compression,—is not so violent as to destroy the power of the nerve. Sensation ensues whenever the extremities, branches, or stump of a divided nerve are irritated, if the connection of the nerve with the brain and spinal marrow is not interrupted. Mechanical irritation of the sensitive nerves of the trunk, and of their divisions, produces merely the varieties of common sensation, namely, pain, and the sensation of touch; irritation of the nerves of sight and the retina, on the contrary, gives rise to no pain, according to Sir C. Bell and M. Magendie, but to the perception of light, as we know from common experience of the effect of pressure or of a blow upon the eye. Mechanical impressions on the auditory nerve, such as are produced by the vibrations of sonorous media, or the jarring of the head and ear in long journeys, give rise to the sensation of sound, but not to pain, of which, it appears, the auditory nerve is not susceptible.

So also, if with a needle we tear, prick, bruise, drag, or stretch a nerve distributed to a muscle, contraction of the latter is produced, and indeed as powerful a contraction as is excited by any galvanic or electric influence. The part of the nerve which is connected with the muscle, will still retain this power, however much we may curtail it; but irritation of the other portion of a divided nerve, that which is in connection with the spinal cord and brain, never excites contractions of the muscles.

Mechanical irritation, when so violent as to injure the delicate texture of the primitive nervous fibres, deprives the nerves of their power of producing sensations, when irritation is again applied at a point more distant from the brain than the injured spot; and in the same way, no irritation of a nerve distributed to a muscle is capable of exciting contraction of the latter, if the nerve has been compressed and bruised between the point of irritation and the muscle; the effect of such an injury being the same as that of division. The sensitive power of a nerve, therefore, is interrupted by any mechanical destruction of its texture between the brain and the part stimulated; and the motor power by the same injury affecting it between the irritated part and the muscle. But the mechanical injury produced by pressure destroys the power of the nerve only locally: irritation applied at any point between the injured part and the brain excites sensation; at any point between the injured part and the muscles, contraction of the latter. If, however, the nerve of a muscle is stretched violently in its whole length, it frequently loses its excitability to the same extent; and even the muscle sometimes in this case loses its irritability, and cannot be made to contract by any manner of stimulus.

b. Temperature.—Heat and cold likewise excite sensation, and contraction of muscles.

When heat is applied to the nerve going to a muscle, or to the muscle itself, contractions of it are produced. These contractions are very violent when the flame of a candle is applied to the nerve, an experiment which I have performed both in frogs and rabbits: while less elevated degrees of heat,—for example, that of a piece of iron merely warmed,—do not irritate sufficiently to excite action of the muscles.

The application of cold has the same effect as heat; thus it is an old observation, that violent contractions of a muscle immediately ensue when cold water is injected into its artery; cold water applied to the surface of a muscle likewise causes it to contract. This action of cold on muscles has been taken advantage of in the practice of medicine; thus, in cases of atony of the uterus, and of uterine hemorrhage after delivery, cold water has been injected into the vessels of the still adherent placenta.

Sympathetic contractions of the iris are produced by drawing cold water into the nostrils. Great degrees of cold and heat, whether their application is sudden or gradual, destroy the nervous energy, and give rise to death or asphyxia. The action of cold or heat very gradually increased sometimes reduces the excitability to a latent state, producing the hybernation and summer sleep of certain animals.

The effect of the local action of an excessive degree of artificial cold or heat on the nerves, is the same as that of destructive mechanical irritation. The sensitive and motor power in the part is destroyed, but all the other parts of the nerve retain their excitability; and, after the extremity of a divided nerve going to a muscle has been burnt, contractions of the muscle may be excited by irritating the nerve below the burnt part: of this I have convinced myself by experiments on frogs and rabbits.

c. Chemical stimuli.—All chemical irritants excite the sensitive power of the nerves, as long as the connection of the latter with the brain and spinal cord has suffered no interruption. Alkalies excite contractions of the muscles likewise when applied to their nerves; many other reagents, particularly the acids and metallic salts, for example, the mineral acids,—sulphuric, nitric, and muriatic acids, bichloride of mercury, and muriate of ammonia, and moreover alcohol, do not excite the slightest contraction of the muscles when applied to the nerves, but must be applied to the muscles themselves. All these substances in a concentrated state destroy the power of the nerve at the point to which they are applied, so that irritation by other stimuli is incapable of exciting their motor action, unless applied between the injured spot and the muscles. All the substances named have likewise a destructive action on the muscular substance, but excite contractions at the moment of their application; the last effect is least marked in the case of alcohol, though I have perceived it some few times in rabbits.

The most violent contractions of the muscles, often much stronger than those produced by the galvanic influence of a single pair of plates, are excited by touching the nerves with alkalies. I, as well as the Baron A. von Humboldt, have seen this effect from caustic potash. Humboldt* has seen the tremor of the muscles continue forty or fifty seconds. He likewise observed that the twitchings of the muscles were produced, although one or more ligatures had been placed on the nerve. In this case the ligatures formed a conducting medium for the alkali. Humboldt could produce no contractions by means of acids; the only substances which, according to him, excite contractions of the muscles when applied to the nerves, are potash, soda, ammonia, opium (?), muriate of barytes, arsenic acid, tartrate of antimony, alcohol (?), and chloric acid (?). I have seen no twitchings of the muscles follow the application of the two last-mentioned substances, or of opium alone, in the state of watery solution, to the nerves. Humboldt employed the tincture of opium, so that the effect might have been owing to the spirit; but yet, in one experiment, which I performed with the tincture of opium, no contractions of the muscles were excited. Chemical irritants introduced into the blood likewise act on the excitability of the nerves. Thus, it is well known that emetic substances introduced into the blood-vessels produce the same effect as when taken into the stomach; tartar emetic and muriate of barytes applied to wounds excite vomiting.†

d. Electric stimuli.‡—Electricity produces in the nerves the same phenomena of reaction that follow the application of mechanical and chemical stimuli. Mechanical violence, as in striking the ulnar nerve at the elbow, gives rise to the sensation of a shock; and the same sensation is felt when an electric discharge is passed through a nerve. But this effect must be regarded merely as a sensation; as a mode of reaction of the nerve, with which its cause, the electricity, must not be confounded. The sensation of the blow or shock is not the action of the electricity, but is the action of the nerve, which becomes the seat of this sensation whenever a violent change in the state of its component parts is produced either by animal or mechanical stimuli, or by electricity.

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* Versuche über die gereizte Muskel-und Nerven-faser. Posen, 1799. Bd. ii. p. 363.

† Scheel, Nordisches Archiv. 2. St. 1. p. 137.—Magendie, sur le Vomissement, pp. 16-30.—Brodie, Philos. Transact. 1812.

‡ See the article by J. Müller in the Encyclop. Wörterbuch der Medicin. Wissenschaften.

The discovery of galvanic electricity in 1790 has been the occasion of the excitability of the nerves being more investigated, namely, by the application of the stimulus of electricity to individual nerves; but in this important agent we have not become acquainted with a fluid similar in its action to the nerves, but merely with a new stimulus of the nerves in addition to those already known. Different metals, and many other bodies, even animal substances of heterogenous composition, when brought into contact, are thrown into a state of electric tension, which ceases when the two bodies are made to communicate at other points through the medium of a conducting subtance,—that is to say, when the circle is closed,—the equilibrium being then restored; and if a reagent for electricity forms part of the circle, the phenomena peculiar to electricity ensue. The leg or any other muscular part of a frog or other animal lately killed being separated from the body, the muscles laid bare, and the nerve dissected out, but left connected by its branches with the muscles, if the part so prepared be laid upon an insulating plate of glass, and two different metals—for example, zinc and copper,—brought into contact with each other, and at the same time with the nerve and muscle, a contraction of the muscle takes place at the moment that the circle is closed, and frequently also when it is again interrupted. The same effect is produced when the two metals, while in contact with each other, are made to touch at the same time the nerve or the muscle only. The experiment, as here described, always succeeds. There are many other more simple modifications of the experiments with galvanism, the knowledge of which we owe to the excellent labours of Aldini, Pfaff, Ritter, and, above all, of Humboldt; but these succeed only when the frogs are in a state of great excitability, namely, before the pairing season, in the cold part of the year after hybernation, and, according to my observation, in the autumn, when the atmosphere is again becoming cold—but not in the summer. These more simple experiments are the most important with reference to the theory of the phenomena produced; they are the following:—

1. *Experiments in which the galvanic circuit is not formed.*—Humboldt has discovered, that when the excitability of the frogs is great, it is sufficient that two portions of different, or even of the same metal, should touch each other, and that one of these be brought into contact with the nerve, no circuit being here formed; and it sometimes happens indeed, though very rarely, (I have, however, myself observed it,) that the frog's limb being very excitable, the mere contact of the nerve with a single homogeneous portion of metal will excite muscular contraction. Pfaff (*Gehler's Physikal. Wörterbuch*, iv. 2, p. 709,) saw twitchings produced by merely bringing the end of the divided nerve into contact with the surface of quicksilver; and I witnessed the same phenomenon several times on touching the nerve with the point of a pair of scissors, or of a plate

of zinc, which I held in my hand, and which consequently was of different temperatures at its two ends.

2. *Experiments with the galvanic circuit.*—The experiments of this kind also may be reduced to a very simple form when the frogs are in a state of great excitability; it is, however, only in the colder seasons of the year,—in the winter, spring, and autumn,—that they succeed. Thus, contractions of the muscles are sometimes produced, as Humboldt discovered, when the circle is formed of animal substances only, or when it is formed of animal substances and a single metal, the place of the heterogeneous metals being supplied by heterogeneous animal substances.

A. The circle may consist of a single metal with the nerve and muscle of the frog's leg. In this experiment I succeeded very frequently and readily in the spring, before the frog's pairing time, and in the latter part of the autumn. (See page 71.) The usual effects were produced still more readily when I interposed a piece of the flesh of a frog between the zinc plate and the muscle of the leg, or when my own body formed part of the circle. (Page 71.)

B. The nerve and muscle of the limb may be connected merely by moist animal substance: the nerve, dissected out, being brought into communication with the muscle by means of a separate piece of muscle fixed to an insulating-rod of sealing-wax, contractions of the muscles are excited. This was first observed by Humboldt, and I have several times performed the experiment with success. I have made the experiment also in another similar but more complicated manner, either closing the circle with my own body, by touching the leg and the nerve of the thigh with my hands, or connecting the leg and ischiadic nerve by means of one or two living frogs, or one or two dead frogs, or by portions of the body of a frog. When sufficient excitability is present, pieces of the body even of a dead and putrid frog are adequate to complete the circle. The same effect is produced likewise, as I have found, by allowing the ischiadic nerve to hang from the leg into a saucer containing either blood or water, (it matters not which,) the fluid and the muscles of the thigh being brought into connection by means of a portion of fresh or putrid flesh.

C. Circles of animal substance merely have been shown by Humboldt to excite twitching, when only the nerve of the limb, and not the muscles, are included in the circuit. Humboldt touched the ischiadic nerve with one hand, and at the same time brought a piece of muscular substance, which he held in the other hand, into contact with the same nerve; twitchings of the muscles were produced. When a piece of ivory was used in place of the muscle no twitching followed.

D. Slight twitches of the muscles likewise ensue sometimes, (though this is the experiment which produces them most rarely,) when the nerve is bent back, and made to touch the muscle with which its branches are organically connected.

The first phenomena of this kind were observed by Humboldt. He stripped a frog of its skin, removed all the parts between the pelvis and end of the spinal cord, with the exception of the nerves of the lower extremities, which were therefore connected with the trunk by the nerves alone, and now carried forwards the lower extremity so as to make the muscle of the thigh touch softly the nerves just mentioned: violent contractions of the muscles were produced. (*Humboldt, über die gereizte Muskel-und Nerven-faser*, i. p. 32.)

To a similar experiment performed by Galvani, it was objected by Volta, that the contractions of the muscles were the effects of the mechanical stretching of the nerve, and consequently were not to be regarded as a galvanic phenomenon. According to my observation, this is likewise the case in M. Humboldt's experiment; I found that the contraction of the muscles frequently took place long before the nerve and the surface of the limb came into contact.

The following may be regarded as the *general conditions necessary for the production of muscular contractions by galvanic influence.*

When the galvanic circle is used, there must be three substances,—two excitors of electricity, and a conductor connecting them. The excitors may be heterogeneous animal substances living or dead, such as nerve and muscle, or muscle and skin. The conductor likewise may be a third animal substance; and even of the same nature as one of the excitors: thus a portion of a nerve, and the muscle and nerve of the limb in which they are organically connected, are adequate to constitute a galvanic circuit; but the muscle and nerve of the limb, without the aid of a third body, whether similar to one of them or not, are insufficient. The nerve being bent back, and brought into contact with the muscle of the leg, causes no twitchings, unless the skin of the leg remains interposed between the nerve and muscle; but a third substance, even though similar in nature to either the muscle or nerve, if not organically connected with them, is capable of forming with them a galvanic circle, and of exciting muscular contractions: this third substance, we have seen, may be a separate portion of nerve or muscle.

When the electro-excitors are both metals, the nerve and muscle of the limb are at the same time conductors (like all moist substances) and electrometers, the nervous principle being excited to action by the stimulus of the electric fluid. They constitute an electrometer in this case, in the same way that inorganic instruments, such as the magnetic multiplicator, are electrometers under similar circumstances. When the nerve and muscle of the limb become electro-excitors, they also act at the same time as an electrometer. When the contractions of the muscles are excited, not by a galvanic circuit, but by the mere application to the nerve of two heterogeneous metals which are in contact with each other, or of a single metal, the nerve must be regarded as an electrometer merely, which indicates the existence of electric tension in two metals of different kinds, or in one metal in a thermo-electric state.

The nerves, when excited by galvanism to the production of muscular contractions, do not act as mere conductors of the electricity.—This is proved by the fact that the muscles can be excited to action by applying both poles of the circle to the nerve, so as to direct a galvanic current through it transversely, if the texture of the nerve is sound between the point galvanised and the muscle; while, if, at any intermediate point, its texture has been destroyed by bruising or by a ligature being applied, the action of the galvanism on the muscles is prevented. A nerve, therefore, which is contused or tied with a moist thread, is unable to conduct the active nervous principle. Nevertheless, when thus injured, it is as good a conductor of electricity as before: for if one of the poles of the galvanic circle is applied above the ligature, and the other below it, the electric current passes through the ligatured part; and the nervous principle of that part of the nerve which is situated between the ligature and the muscle being within the circle, and therefore irritated by the electric current, excites the muscles to contract. It is a remarkable circumstance, which Humboldt first observed, that when it is desired to excite the contraction of a muscle by applying one pole of the galvanic circle to the muscle, and the other to its nerve which has been previously surrounded with a ligature, a certain extent of nerve must be left free between the point where it is tied and the muscle; for, if the ligature is applied too close to the muscle, the galvanic current fails to produce any effect till the nerve has been dissected out from the muscle for a certain extent. The effect on the muscles is likewise prevented, even when there is between them and the ligature a free portion of nerve, by surrounding this with some pieces of muscle, wet sponge, or metal. It appears, therefore, that, in the mode of operating mentioned by Humboldt, the nerve between the muscle and the ligature must be insulated.

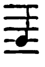
In all experiments in which the legs of frogs are submitted to galvanism, the contractions of the muscles are stronger in proportion to the length of the nerve going to them (Pfaff). The effect of the galvanic stimulus extends always in the direction from trunk to branches: when both poles of a galvanic circle are applied to a nerve, no contractions are excited in muscles supplied by branches which come off from the nerve at a higher point; but all the muscles are thrown into contraction which receive branches from the nerve below the part galvanised. The strength of the muscular contraction always depends on the number of nervous fibres which lie within the galvanic circle: hence the contraction is most trifling when the muscle alone is included in the circle; only that part of the muscle then acts, the nervous fibres of which are exposed to the galvanic current. Ritter and other physiologists have observed that, during the gradual loss of irritability which takes place in parts separated from the body, all parts of the nerve do not fail in their irritability with the same rapidity, but that the decline advances by degrees from the cerebral extremity of the nerve along its branches.

Some nerves, which are distributed to muscles, are nevertheless incapable of exciting muscular contractions under the influence of the galvanic stimulus, both poles of the circle being applied to the nerves themselves.—This is the case with the posterior roots of the spinal nerves, while the anterior are excessively susceptible of the galvanic stimulus. I have likewise shown by experiment that the same stimulus excites no motor action when applied to the gustatory branch of the fifth nerve. This extraordinary result may be explained in either of two ways: namely, by supposing that the motor roots alone have the vital endowment of causing the muscles to contract, or by admitting, what is possible, that the motor roots transmit impressions in the centrifugal direction only, the sensitive roots only in the centripetal direction.

The stimulus of galvanism excites in all the organs of sense different sensations—in each organ, namely, the sensation proper to it.—The peculiar taste produced by including the tongue in a galvanic circle is well known. When a piece of zinc is applied to the point of the tongue, and silver to its back part, an acid taste is produced, which is rather sharp or alkaline when the metals are reversed. The same result may be obtained by using only one metal and a moist substance as an exciter of electricity, as in the following experiment described by Volta:—A pewter cup filled with soap and water, lime and water, or, still better, with a moderately strong ley, being held with one or both hands previously moistened with water, and the point of the tongue brought into contact with the fluid, the sensation of an acid taste is immediately perceived. Pfaff (*loc. cit.*) remarks, with reference to this experiment, that it appears to prove that the taste excited by the action of galvanism on the tongue is not owing to the decomposition of the muriate of soda of the saliva, and the disengagement of the acid at the positive, and of the alkali at the negative pole; for here the tongue being brought into contact with an alkaline fluid, the saliva could not have become acid. In fact, the taste produced by galvanism is, like all sensations of taste, the result of the specific reaction of the gustatory nerve; a particular taste therefore is only an internal condition excited in the nerve, and not a property of the stimulus which produces it. It has not at present been much observed whether peculiar smells are produced by the application of galvanism to the olfactory organ; Ritter, (*Beiträge zur näheren Kenntniss des Galvanismus*, p. 160,) however, has perceived them; and it is a known fact, that the electricity excited by friction gives rise to the smell of phosphorus.

In the eye, a feeble galvanic current excites the special sensation of the optic nerve, namely, the sensation of light. Ritter and Purkinje have shown how the sensations of colours are excited in the eye. The sensation of light in the eye thus produced is not a development of the matter of light, but is merely the reaction of the optic nerve, which is susceptible of the sensations of light and colours only, but not of pain. It is a particular state of the optic nerve, just as pleasant and painful sensations are particular states of the nerves of common sensation. This view of the nature of the appearances of light in the eye has been established by the experiments of Purkinje and myself, and is also adopted, we observe, by physical inquirers of the first rank,—for example, by Pfaff.

In the auditory nerve, electricity produces the sensation of sound. Volta states that, when the poles of a battery of forty pairs of plates were applied to his ears, he felt a shock in his head, and a few moments afterwards perceived a hissing and pulsatory sound like that of a viscid substance boiling, which continued as long as the circle was closed. (*Philos. Transact.* 1800, p. 427.) Ritter relates that, on closing the galvanic circle when both his ears were included in it, he was sensible of the sound of G treble: if but one ear was in the circuit, and the positive pole applied to it, the sound was lower than G; if the negative pole was applied to the ear, the sound was higher.



2. *Of the changes produced in the excitability of the nerves by stimuli.*

Thus far we have considered merely the reaction of the nervous forces under the influence of stimuli. We have now to investigate the changes which these forces themselves undergo. All stimuli, which, by producing changes in the peculiar matter of the nerves, excite reaction of them, are also capable of modifying their state of excitability. Reaction is always attended with an expenditure of power; it is the result of the change produced in the organic matter, which is greater in proportion to the duration of the excitement. During a normal state of life the excitation is never so great that, in consequence of the change induced, the faculty of manifesting the vital faculties is perceptibly injured. The daily changes in the system, consequent on the action of stimuli, are counterbalanced by the processes of nutrition. But if the action of the stimulus is more violent, a longer time is required for restoration to be effected, and the intensity of the excitement may be such as to exhaust the whole vital force of the organ. We are daily made conscious of these laws in the exercise of our power of muscular motion, of the generative function, and of the mental faculties, they are also exemplified in the effects of the immediate application of stimuli to the nerves. If a nerve is submitted to the long-continued action of galvanism, the muscular contractions, which are excited, become more and more feeble, until at length they cease, and some time elapses before they can be re-excited; the nervous power, in fact, must first have been restored by the contact of the blood. It is the same with sensations. The longer the eyes are fixed upon a coloured object, the less distinct becomes the colour, till at length it is lost and the object appears gray; the retina acted on by the stimulus of light becoming exhausted, and at last insensible. [In all these cases the exhaustion of the nervous excitability is the effect of the previous excitement, and not of any peculiar action of the exciting influences. The irritability may, however, be exhausted immediately, without previous excitement, by a foreign agent acting at the cost of the organic combination, and destroying the nerve while it annihilates the nervous power. This is the effect, for instance, of the most intense degree of electric action, as in lightning; of mechanical pressure likewise, by which the nerve and its primitive fibres are crushed: such also is the action of chemical agents, which destroy the organic combinations of the nervous substance, and decompose it; for example, of the mineral acids, the metallic salts, and pure alcohol.]

If this external influence acts on all the nerves of the body simultaneously, as is done by the electricity in lightning or in the discharge of a strong battery, or if the entire length of a nerve is extended and stretched, the irritability of the whole system or of the whole nerve is destroyed. If the influence be such as affects only one point of the nerve,—as when it is submitted to a caustic substance, pressure, or contusion,—the nervous power is destroyed in this point only, and between it and the muscle the nerve is still susceptible of being excited to motor action.

Heat and cold, when their action is not carried beyond a certain degree of intensity, nor continued beyond a certain time, are stimulants; but if their action be more violent and long continued, they have a contrary effect.

Cold, which, like heat, is capable of exciting inflammation and gangrene, benumbs the limbs, or deprives them of sensation and motion. This effect may be either local or general. The local action of heat, when it does not produce inflammation and mortification, appears to excite, and not to benumb; but the general long-continued influence of heat is also productive of exhaustion of the nervous functions.

In the case of some influences which destroy the nervous power, a transitory excitement seems to precede the destruction of the excitability; this is the case, for example, when a nerve is crushed, or when an alkali is applied to it. The same phenomena of excitement are still more evident in the effects of a great part of the substances called narcotics, the principal action of which appears to be the production of a change in the composition of the nerves, and, when very intense, the abolition of the nervous power.

A large class of substances have, in the state of solution, a specific influence on the nerves, destroying their power, although they have no particular chemical properties as tested by reagents, and have not a solvent action on organic compounds generally. These are the "*alterantia nervina*," or "narcotics." They all produce a change in the component matter of the nerves. Some—for example, opium and nux vomica—are in small doses stimulant, their depressing action being less marked; but all, when given in large doses, immediately deaden the excitability by producing change in the nervous matter. That such a change, not recognisable by our senses, nor by chemical tests, is really produced in the nervous matter, is probable, and it is necessary to adopt the supposition: but the only sign which we have of it is the loss of nervous power; the nerve which is paralysed by the narcotic—at least, when a watery solution of a mere narcotic, for instance, of opium, is used,—differs externally in no respect from a sound nerve. But that narcotic poisons are able to produce changes in the nervous matter is proved by the observation of Fontana, that some of them,—the Ticunas poison, and the poison of the viper,—when added to the blood, fresh drawn from the body, deprive it of its property of coagulating; while the poison of the viper also has the contrary effect when introduced into wounds in living animals,

; the coagulation of the blood in the vessels even during

re investigating more closely the action of narcotics on the
, we will inquire whether there are not substances capable of
cing exaltation of their quality of excitability.

Renovating stimuli.—Earlier experiments seemed to favour
onclusion that many substances have the property of increasing
nervous power, and they thus promised results of great im-
ance to practical medicine.* But the more powerful action of
vanism, after the nerves have been moistened with solution of
orine or with alkaline solutions, does not prove that these fluids
crease the excitability of the nerves, but merely that the galvanic
tion is stronger; and Pfaff (*Nordisch. Archiv.* Bd. i. p. 17,) has
nown that the majority of such substances act by forming part of
he galvanic circle, and by increasing the energy of the galvanic
stimulus; they act, therefore, though more powerfully, yet in the
same manner as water, which as a conductor is necessary to gal-
vanic action. *Medicine has ceased to expect any benefit from
medicinal substances in the way of strengthening the nervous
energy; the pretended virtues of such remedies are displayed no-
where but in the treatises on Materia Medica.*

There are stimulants, it is true, in abundance; but they can
strengthen the nerves only by promoting the reproductive process of
nutrition in them. The remarks on the action of stimulants generally
in the Prolegomena have equal force in the case of stimulants of the
nerves.

2. *Alterant stimuli.*—Such are the narcotics, which, while they stimulate, seem to produce a change of composition in the nervous matter. It is by virtue of the latter property that in small doses they are useful in cases of paralysis, where they either remove slight deviations from the normal state of the nervous matter, or produce such a change in it as enables nature to effect the cure. A more violent action of the alterantia nervina, or narcotics, is immediately destructive.

The change produced in nerves by the immediate application to them of a poison, causing paralysis, is not preceded nor accompanied by any signs of excitement, such as muscular twitchings. The application to the nerves themselves, in a rabbit, frog, or toad, of a watery solution of opium, of strychnine, or of spirituous extract of nux vomica, has, in my experiments, never excited muscular contractions; and I doubt if a narcotic applied directly to a nerve ever excites contractions of muscles; it must, I believe, act through the medium of the spinal marrow and brain. Strychnine, applied in powder to the moist spinal cord of the frog, excites no twitchings of the muscles; it must first enter the circulation, and thence act on the spinal cord, which transmits the influence to the nerves. Hence, when an animal is poisoned with opium or strychnine, if the nerves of an extremity are divided, the spasms in that limb cease; and if a portion of the spinal cord of an animal is destroyed before poisoning it with the upas ticuti, or angustura, all the parts which received their nerves from that part of the cord are exempted from the convulsive muscular contractions which ensue. These experiments prove incontestably that the narcotics do not excite contractions of the muscles by their direct action on the nerves, but through the medium of the spinal cord and brain.

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* See Von Humboldt's Versuche über die gereizte Muskel-und Nerven-faser.

There remains, however, another question for consideration; it is, whether narcotic poisons cannot, by their own action on the nerves, exhaust the irritability of the latter by an influence analogous to that of chemical stimuli. This question has been incorrectly confounded with the former, and an error has been committed in giving to both the same answer.

Narcotic poisons, when they paralyse the sensitive and motor powers of the nerves, must usually act, through the medium of the blood, on the brain, spinal marrow, and nerves; having been absorbed into the capillary vessels. Their second mode of action, which is less rapid and more circumscribed, is by destroying locally the nervous power.

Action of narcotic poisons through the medium of the blood.—It was formerly imagined that the general effects of the local application of narcotic poisons arose from the local injury being propagated through the nerves.

But the experiments of various physiologists, detailed at pages 253–254, tend to prove that the rapid general action of local poisoning is not effected through the medium of the nerves; but that the poison enters the blood, and is with it distributed to all the organs of the body. It is likewise susceptible of proof that *the general symptoms of poisoning are principally owing to the action of the blood, impregnated with the deleterious substance, on the central organs af the nervous system.*

1. After death produced by poisoning, the nerves and muscles are found to retain their irritability for a considerable time.

2. Ligature of the arterial trunk of an extremity does not exempt the latter from participating in the general effects of a poison subsequently administered, of which the action produces muscular spasms. (See *Lund, Vivisectionem*, p. 109.) Paralysis of the heart, which Wilson Philip observed to be caused in frogs by the application of infusion of tobacco or opium, will not, as Lund remarks, account for the symptoms of general poisoning; for frogs live many hours after their heart is cut out. The lungs, again, are not the organs principally affected; for supplying artificial respiration does not save the animal. While, on the other hand, if, in an animal poisoned with opium, strychnia, upas, or angustura, the nerves of an extremity are divided, the spasms in that part cease; so, also, destruction of a portion of the spinal cord puts a stop to the convulsions in parts, the nerves of which arise from that portion of the cord. Opium, and the poison of serpents, appear to affect the brain and spinal cord equally: strychnia and the various poisons of the genus strychnos, and the poison of angustura, act more especially on the spinal cord;

ducing paralysis of the hands, are also well known. To place the local action of narcotic poisons on the nerves beyond doubt, I dissected out the ischiadic nerve in a frog for a considerable extent, and let it hang in a solution of acetate of morphia; after a little time I found that the end of the nerve had wholly lost its excitability. The same was the effect of immersing the muscles in solution of opium, as Humboldt had already shown. I dissected out the ischiadic nerve in toads, and left the leg connected to the body by this nerve only, which, together with the leg, I then immersed in a strong watery solution of opium; in a short time the nerves and muscles lost all susceptibility of the influence of galvanic or chemical stimuli.

The local influence of narcotic poisons on the nerves is therefore certain. We must now inquire whether this effect extends beyond the nerves and muscles immediately affected. I have instituted direct experiments which prove that the local action of narcotics on nerves which are laid bare, and insulated by dissection from other parts, remains limited to the point of application.

1. In the first place, when the trunk of the ischiadic nerve is immersed in solution of acetate of morphia or opium, the paralysis does not extend to the muscles of the leg and their nerves. A mechanical or galvanic stimulus excites no contractions of the muscles when applied to the upper extremity of the nerve; but it does when applied to the lower part of the nerve, or to the muscles themselves. *The narcotic action, therefore, is not propagated from the trunk of a nerve to its branches.*

2. *The narcotic action does not react from a particular point of a nerve on the brain.*—I have already related experiments in which the nerves of the lower extremity in toads had been deprived of all excitability by the action of narcotics, but in which the other parts of the body remained uninfluenced. Other observations, however, render it probable that a gradual reaction does take place; for, whenever the nervous power of a part is exhausted, as by inflammation and mortification, exhaustion of the nervous power of the whole system gradually ensues. Hence we perceive an important difference in the action of different influences on the nervous system; for,

a. The stimuli, which excite a manifestation of the nervous force, act instantaneously through the whole length of the fibres which are irritated at any one point. The contraction of the corresponding muscles takes place at the very moment that the stimulus affects the nervous fibres, at whatever point of their course it is applied between the muscle and the trunk of the nerve; and sensation is excited with equal rapidity.

b. The action of influences, on the contrary, which exhaust the excitability or power of the nerve, extends from its original seat very gradually to the sound parts of the nerve; and general symptoms slowly follow.

Thus, loss of sight in an eye is gradually followed by atrophy of the optic nerve, which is likewise an effect of atrophy of the optic thalamus. Tabes dorsalis extends from below upwards. A violent injury of individual nerves is succeeded by a morbid state of the whole spinal cord,—namely, by tetanus.

3. *Dependence of the nerves on the brain and spinal cord.*

It was known that, after the division of a nerve, the portion cut off from communication with the brain retains, for a certain time, its excitability; but the questions how far connection with the brain and spinal marrow is necessary for the longer preservation of the irritability of the nerves, and whether the muscles retain their irritability when their nerves no longer communicate with the central parts of ther nervous system, could not hitherto be answered with certainty, and had indeed been seldom mooted. Nysten (*Recherches de Physiol. et de Chim. Pathol.*) had asserted that the muscles of patients who died a short time after an apoplectic seizure preserved their irritability, and contracted under the influence of the galvanic stimulus, although the functions of the brain had been paralysed. I had good reason, however, for believing that in such cases the nerves retain their power only for a short time, losing it entirely after a longer interval; for, in experiments on the reproduction of the nervous tissue in a rabbit, I had once observed that the lower portion of the nervus ischiadicus, which I had divided some months previously, had lost all its excitability; and a similar fact had been before observed by Fowler. I have since performed, in conjunction with Dr. Sticker, new experiments, (see *Dr. Sticker's paper in Müller's Archiv.* Bd. i. 1834,) which have completely confirmed that supposition.

These experiments prove at least that, when the communication of the nerves with the brain and spinal cord is wholly cut off, they gradually lose the power of exciting the muscles to contraction, while the muscles lose their irritability. The result would, however, have been still more decisive if, in place of a single pair of plates, a small galvanic battery had been employed to stimulate the nerves and muscles. That, and that alone, would have enabled us to determine with certainty whether all the power of the muscles, in two of the cases, had been lost. The experiments as they were made, however, prove distinctly enough the necessity of communication with the brain for the preservation of nervous and muscular power. We may also conclude from them that if, after the division of a nerve, the excitability of the lower portion and the irritability of the muscles are restored, the nerve itself must have been completely reproduced, and that this will not have been the case if the nerve and muscle do not regain their vital properties.

Some interesting observations by Dr. Marshall Hall (*Medico-Chirurg. Transactions,* vol. xxii. and *Müller's Archiv.* 1839,) have explained the apparent discrepancy between the results of the foregoing experiments, and the well known facts, that strychnine administered to paralytic patients frequently excites movements soonest and most powerfully in the paralysed limbs, and that paralysed parts are subject to convulsions and tonic spasms. Dr. Hall confirms the statement that lesion of nerves at any point between the spinal cord and muscular parts to which they are distributed, causes the irritability of those parts to diminish very rapidly; but he shows, on the other hand, that when the influence of the brain only is cut off, either by division of the cord in animals, or by disease affecting the dorsal part of the cord or the cerebrum itself, the paralysed parts, being still in connection with the spinal cord, not only retain their irritability, as was stated by Prochaska, Nysten, and other physiologists, but can be excited to action by a galvanic stimulus much too feeble to cause motion in the corresponding sound parts. This latter result was obtained even in a chronic case of hemiplegia, where the paralysed limbs were much emaciated; so that the loss of excitability in muscles and nerves cut off from communication as well with the spinal cord as with the brain, cannot, Dr. Hall concludes, depend merely on their nutrition being interfered with, but the spinal cord must exert, independently of the brain, a direct influence in keeping up the excitability of the nerves and muscles connected with it. The question, why should motions be so much more easily excited in parts deprived of the influence of the brain only, than in parts not paralysed, will come under consideration in the chapter on the Functions of the Spinal Cord.

CHAPTER III.

OF THE ACTIVE PRINCIPLE OF THE NERVES.*

The older physiologists had no determinate ideas regarding either the nature of the nervous principle or the laws governing its action. They supposed that what they denominated "nervous spirits" were transmitted from the brain through the nerves and their ramifications to the different organs. And when the actions of common electricity, and the modes in which it is conducted, became more fully known, physiologists imagined that the action of the nerves was rendered more intelligible by comparing them with electric apparatus. But it was not until the discovery of galvanism that the grounds of this and similar hypotheses were submitted to an exact inquiry.

Although it is now certain that the phenomena produced in animals by galvanism are not due to an animal electricity, still many physiologists and men of science have not ceased to regard electricity and nervous power as principles in a certain degree similar. A closer inquiry, however, shows that they are totally different. The experiments of Dr. Ure, and those of Dr. Wilson Philip, have among others given rise to misconceptions. In Dr. Ure's experiments, one of the wires connected with a galvanic battery of two hundred and seventy pairs of plates was applied to the spinal cord laid bare in the body of a criminal who had died, by hanging, an hour previously, while the other wire was applied to the ischiadic nerve. At the moment that the circle was closed, the muscles of the trunk were thrown into contraction as in a violent shudder. The motions of a laboured respiration, with the alternate rising and falling of the abdomen, were imitated by including between the wires the phrenic nerve and diaphragm, and alternately opening and closing the circle. In the same way horrid grimaces of the features were produced. But in all this there was nothing more extraordinary than in the most common galvanic experiment, except that the human body was the subject of it. The experiments of Dr. Wilson Philip, in like manner, by no means justify the conclusions drawn from them.

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* From J. Müller's article in the Encyclop. Wörterbuch der Medic. Wissensch.

The neurilema and the surrounding parts being moist, electricity would not remain insulated in the nerves, were it in action in them. It has, indeed, been imagined that the nerves have an insulating property. Fechner compares the nervous fibres to conducting wires covered with silk. But the neurilema itself is an excellent conductor of the galvanic fluid, and the nerves, as we shall show, have not a greater conducting power than other moist animal textures; for the galvanic current does not necessarily follow the ramifications of the nerves; it is only the nervous principle which takes that course. The galvanic current is conducted off from the nerves by the neighbouring tissues as readily as it is conducted by the nerves themselves, if a more direct course to the pole is thus afforded. Again, the passage of the nervous principle is interrupted by a ligature, while this has no effect on the transmission of the galvanic fluid.

Electricity is known by the bodies which insulate it, and which are conductors of it; these are its sole and certain tests, and in respect of them the nervous principle differs from it, and consequently cannot be identical with it. Other proofs, however, derived from properties of the nervous principle already alluded to, may be adduced; such as the following:—

Nerves, even when perfectly dead, are, like all moist animal textures, still capable of conducting the galvanic fluid, though they have lost the power of exciting contractions in muscles.

The experiments of myself and Dr. Sticker have shown that, when the vital influence of the nerves on the muscles has been interrupted for any considerable period, the stimulus of a simple galvanic circle is incapable of exciting their contraction. We found this to be the case in Mammalia, in which we had several months previously divided the nerves in such a manner as to prevent their perfect reunion.

The discovery of electro-magnetism has furnished us with the most delicate galvanometers.

Vavasseur and Beraudi[*] were deceived when they asserted that needles passed through the nerves of a living animal become magnetic, so as to attract iron filings. So also was M. David when he thought that galvanic phenomena were elicited by similar means.

The most recent experiments performed with the aid of the galvanometer are those of M. Person,[†] who, although the action of his instrument was most delicate, failed, like Prevost and Dumas, to detect electric currents in the nerves.

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[*] Annali Universali di Med. Maggio, 1829; and Froriep's Notiz. No. 538.

[†] Sur l'hypothèse des Courans Electrics dans les Nerfs. Journ. de Physiol. t. x. 1830.

The conclusions which must be drawn from an extended investigation of the question, are:—1. That the vital actions of the nerves are not attended with the development of any galvanic currents which our instruments can detect. 2. That the laws of action of the nervous principle are totally different from those of electricity. 3. To speak, therefore, of an electric current in the nerves, is to use quite as symbolical an expression as if we compared the action of the nervous principle with light or magnetism. Of the nature of the nervous principle we are as ignorant as of the nature of light and electricity; while with its properties we are nearly as well acquainted as with those of light and other imponderable agents. However much these various principles differ from each other, the same question applies to all; namely, are their effects produced by currents of an imponderable matter travelling through space, or by the undulations of a fluid? The decision as to which theory is correct in the cases of the nervous principle, is at present a matter not affecting the study of the laws of its action; just as the laws of optics must remain the same, whichever theory of the nature of light be adopted.

SECTION II.

OF THE NERVES OF SENSATION, THE NERVES OF MOTION, AND THE ORGANIC NERVES.

CHAPTER I.

Of the sensitive and motor roots of the Spinal Nerves.[*]

The fact that the same nerves supply the body with sensitive and motor power, and that one of these functions of a nerve may, in consequence of paralysis, be lost while the other is preserved, is one of the most important in Physiology. Sir Charles Bell first conceived the ingenious idea that the posterior roots of the spinal nerves, which have upon them a ganglion, are the source of sensation; the anterior roots, the source of motion; and that the primitive fibres of these roots after their union are mingled in one trunk, and thus distributed for the supply of the skin and muscles. This view he proposed in 1811, in a treatise entitled "An idea of a New Anatomy of the Brain, submitted for the Observation of the author's friends." Eleven years later, the same theory was advanced by M. Magendie, to whom, however, the merit belongs of having first subjected it to the test of experiment in the case of the spinal nerves.[†] M. Magendie maintained, as the result of his experiments, that division of the posterior roots of the nerves deprived the corresponding parts of the body of sensation only, while division of the anterior roots deprived them of motion. M. Magendie's results were only approximative. He asserted that the posterior columns of the spinal cord, and the posterior roots of the nerves, supplied sensation principally; the anterior, principally motion; but that the latter were not wholly devoid of sensitive power. Thus, in his experiments, the application of galvanism to the posterior roots of the spinal nerves after their separation from the spinal cord, excited contractions of the muscles, though these were but feeble; while the same stimulus applied to the anterior roots gave rise to violent muscular spasms.* These experiments, performed on the higher animals, are the most cruel that can be imagined. The extensive wound necessary for laying open the spine in sufficient length to enable the operator to divide the roots of all the nerves which go to the posterior extremities, produces a great shock to the system, is attended with very great hemorrhage, and death inevitably follows in a short time, before satisfactory results can be attained. Great, therefore, as was the interest which Sir C. Bell's theory, thus newly illustrated by M. Magendie's experiments, excited, a satisfactory confirmation of the results was still wanting.

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[*] Principally derived from the papers of J. Müller in Froriep's Not. Nos. 646 and 647, and in the Annal. des Sc. Nat. 1831.

[†] This statement is incorrect. Sir C. Bell, in his first Essay above referred to, had recorded an experiment on the roots of the spinal nerves in the following words:—"On the laying bare the roots of the spinal nerves, I found that I could

After so many unsuccessful attempts to verify M. Magendie's assertion, I began to doubt the possibility of obtaining a decided and satisfactory result from all such experiments. Desmoulins and Magendie themselves, however, have merely said, that, in the one case *nearly all sensation*, in the other, *nearly all power of motion*, is lost. In deciding a question absolutely, no half results, no approximatives, are sufficient. The theory of Bell was extremely ingenious, but its truth appeared to me still to require demonstration; even Magendie

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cut across the posterior fasciculus of nerves, which took its origin from the posterior portion of the spinal marrow, without convulsing the muscles of the back; but that, on touching the anterior fasciculus with the point of a knife, the muscles of the back were immediately convulsed." He seems, it is true, to have supposed at first that the anterior roots contained nervous fibres for sensation as well as those for motion, while the posterior roots governed the "operations of the viscera," and "the secret operations of the frame," and "united the body together." Subsequently, however, by observing the modes of origin and distribution of the cerebral nerves and the different effects of lesions of them, he was led to the more correct inference, that the single-rooted nerves connected with the anterior columns of the spinal cord and corresponding parts of the brain, and the anterior roots of the double-rooted nerves were exclusively motor, and that the posterior roots connected with the posterior columns of the cord were sensitive. That he arrived at this conclusion before M. Magendie, or any other physiologist, had taken up the inquiry, rests on the evidence contained in Mr. John Shaw's Manual of Anatomy, published in Sept. 1821; and in several papers by that gentleman, which appeared in the Quarterly Journal of Science, Dec. 1821, and March, 1822; and in the Medico-Chirurgical Transactions, April, 1822; while the date of M. Magendie's first publication on the subject was August, 1822. A very clear and very impartial statement of the facts bearing on the question of priority in this important discovery will be found in the Brit. and For. Quarterly Review for January, 1840.—*Translator.*

* J. de Physiol. ii. 276. Compare Desmoulins et Magendie, Anat. et Physiol. des Systèmes Nerveux. Paris, 1825, p. 777.

had not decided it satisfactorily; and it is perhaps impossible to decide it with certainty in the higher animals. This opinion, that the theory of Bell had not been properly established by experiment, was also held by Prof. E. H. Weber. (See page 283 of his excellent edition of *Hildebrandt's Anatomie.*)

The happy thought at length occurred to me of performing the experiment on frogs. These animals are very tenacious of life, and long survive the opening of the vertebral canal. In them, also, the nerves retain their excitability for a very considerable time, and the large roots of the nerves of the posterior extremities run a long distance within the cavity of the spine before uniting. The result was most satisfactory. The experiments are so easily performed, so certain and conclusive, that every one can now very readily convince himself of one of the most important truths of physiology.

To lay open the spine, I make use of a small pair of bone-nippers, which cut sharply at the edge and points. The operation is completed in a few minutes, without any injury to the spinal cord. The frogs remain quite lively, and leap about as before. As soon as the spinal canal and the membranes are laid open, the thick posterior roots of the nerves, given off to the lower extremities, come into view. They should be carefully raised with a cataract needle, without including any of the anterior roots, and cut off close to the spinal cord. The end of one of the posterior roots being now seized with a pair of forceps, and the root itself irritated repeatedly with the point of the needle, not the slightest contraction of the muscles of the posterior extremities ever ensues. The same experiment may be repeated on the very large posterior roots of the nerves of the anterior extremities, and the same result will be obtained.

One of the anterior roots of the nerves of the lower extremity, which are equally as large as the posterior, is now raised with the needle out of the vertebral canal, and it is found that the slightest touch of these anterior roots excites the most powerful contractions of the whole limb. Having cut them through at their insertion into the cord, the extremity of one is seized with the forceps, and the needle used to irritate it as in the case of the posterior root. Each time that the point of the needle is applied, most distinct twitchings of the muscles take place.

These experiments may be repeated on a large number of frogs, and they will most convincingly prove that *it is quite impossible to excite muscular contractions in frogs by irritating mechanically the posterior roots of the spinal nerves; while, on the other hand, the slightest irritation of the anterior roots immediately gives rise to very strong actions of the muscles.*

As long as both roots of the nerves are in connection with the spinal cord, the traction experienced by the cord itself, when the posterior roots are raised, may cause the production of muscular twitches in the limbs; such effects, however, are quite independent of the action of the posterior roots, and depend solely on the irritation communicated to the anterior roots by the spinal cord in consequence of the mechanical violence which this has suffered. Hence, if the latter roots have been previously divided, no mechanical irritation of the spinal cord itself, or of the posterior roots connected with it, excites the slightest muscular contractions.

The experiments with the galvanic stimulus of a single pair of zinc and copper plates are equally conclusive.

The application of galvanism to the anterior roots of the spinal nerves, after their connection with the cord is divided, excites violent muscular twitchings; the same stimulus applied to the posterior roots is attended with no such effect. This result is very remarkable, and is what I did not at all expect: for I imagined that, although the posterior roots are endowed with sensation merely, they might still conduct the galvanic fluid to the muscles; and when a powerful galvanic pile is employed, this is inevitably the case (as in Magendie's experiments), the strong galvanic current being conducted by the posterior root of the nerve as by any animal substance. The stimulus of a single pair of plates, however, while it causes the anterior roots of the nerves to give rise to muscular contractions, has no such influence when applied to the posterior roots. In this experiment it is necessary to be very cautious that the plates are brought into contact with no other parts than the nerves.

The experiments may be performed on frogs in the manner adopted by Sir C. Bell and M. Magendie, and the results will be as decided as in those just detailed. If in the same frog the three posterior roots of the nerves going to the hinder extremity, be divided on the left side, and the three anterior roots on the right side, the left extremity will be deprived of sensation, the right of motion. If the foot of the right leg, which is still endowed with sensation but not with the power of motion, be cut off, the frog will give evidence of feeling pain by movements of all parts of the body except the right leg itself, in which he feels the pain. If, on the contrary, the foot of the left leg, which has the power of motion, but is deprived of sensation, is cut off, the frog does not feel it. This experiment is the most striking of all, and the result is decisive; because, on account of the small number and large size of the roots of the nerves going to the posterior extremity in the frog, we can be certain that all are divided.

The foregoing experiments leave no doubt as to the correctness of Sir C. Bell's theory.

I may further remark that the section of the posterior roots is frequently attended with very distinct manifestations of the sensation of pain in the anterior part of the body.

The difference with regard to motor and sensitive properties, which has been established so clearly in the case of the anterior and posterior roots of the nerves, has not been by any means demonstrated to exist between the anterior and posterior columns of the spinal cord.

CHAPTER II.

OF THE SENSITIVE AND MOTOR PROPERTIES OF THE CEREBRAL NERVES.

We shall not here enter in detail into the subject of the physiology of the individual cerebral nerves, but shall merely inquire how far they agree with or differ from the spinal nerves.

The cerebral nerves may be arranged in the following classes:—

1. *The nerves of special sense:* the olfactory, optic, and auditory nerves.

2. *Mixed nerves with double roots:* the nervus trigeminus, nervus glosso-pharyngeus,* the nervus vagus *cum accessorio*, and, in several Mammalia, the nervus hypoglossus.

3. *Single-rooted nerves, for the most part of motor function, which are either themselves entirely motor, and receive sensitive fibres from other nerves, or which, if their roots contain sensitive fibres, still cannot be classed with the double-rooted spinal nerves.* These are the nervus oculo-motorius, the trochlearis, the abducens, and the facial nerve.

The nerves of the last two classes require a particular consideration.

Mixed Cerebral Nerves with double Roots.

Nervus trigeminus.—The two roots of this nerve, namely, the *portio major*, which expands to form the ganglion Gasseri, and the *portio minor*, which has no ganglion, and passes under the ganglion of the portio major to join the third branch which issues from it, are well known. The first and second divisions of the nerve, which arise wholly from the ganglion of the portio major, are probably purely sensitive. The third division, which is formed in part by the portio minor, and receives another portion of its fibres from the Gasserian ganglion, is both motor and sensitive.

The experiments of Sir C. Bell, M. Schoeps, Mr. Mayo, and myself, prove, therefore, that all the branches of the first and second divisions of the nervus trigeminus are nerves of sensation, and not nerves of motion.

The third division is evidently both sensitive and motor, like the spinal nerves, which are likewise composed of a root provided with a ganglion, and of another on which no ganglion is formed. Its function is shown by its distribution. This third division of the fifth, rather than the whole nerve itself, is analogous to the spinal nerves.†

The masseteric, deep temporal, buccinator, pterygoid, and mylohyoid branches, those given to the levator and tensor palati muscles, and the nerve of the tensor tympani, which arise either immediately or mediately from the third division of the fifth, are evidently motor. But the fact of the masseteric giving branches to the maxillary articulation shows that they contain sensitive fibres likewise.

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* Recent experiments render it most probable that the glosso-pharyngeus is a nerve of sensation alone.

† The motor function of the third division of the fifth nerve was first proved experimentally by Mr. John Shaw. (Med. and Phys. Journ. 1822, October.)

That the branch which issues from the mental foramen is a nerve of sensation, is proved by the case observed by Sir C. Bell, in which it was injured in the extraction of a tooth, and the lower lip in consequence rendered insensible. It can likewise be proved very satisfactorily that the gustatory branch, although it is distributed to the muscular substance of the tongue, is a sensitive nerve, and has no motor power.

Desmoulins had made the remark that, if the gustatory nerve is stretched in a dog, the animal utters a cry, the tongue remaining motionless; and that the application of galvanism to the nerve after death causes no motion of the tongue. This last experiment I have instituted (see *Froriep's Notiz.* No. 647,) on rabbits during life; the nerve being divided, and then irritated with a needle, or with the stimulus of a battery of sixty-five pairs of plates: the result was as Desmoulins states. Magendie also has observed that division of the gustatory nerve is followed by loss of sensation, without loss of motion in the tongue. I have satisfied myself that this nerve is capable of the sensation of pain, and it will be shown at a future page that it is also the nerve of taste.

From the facts which we have stated, it results that the fifth nerve, by virtue of its greater root, supplies all the anterior and antero-lateral parts of the head with common sensation, there being other nerves for the special senses of smell, sight, and hearing; and that, by virtue of its smaller root, it is the motor nerve of all the muscles engaged in mastication. Hence, in Magendie's experiments, the division of the trunk of the nerve put a stop to all the movement of mastication, and deprived the whole anterior part of the head, the eye, nose, and tongue, of common sensibility; and hence disease of the trunk of the nerve, or of its roots, as has been observed by Bell, Magendie, and Serres, is attended with the same results. The result of division of the nerve within the cavity of the cranium, an experiment performed by Magendie and repeated by Eschricht, was loss of sensibility of the entire side of the head. The mucous membrane of the nose, as well as the conjunctiva, were rendered insensible to puncture, and to chemical irritants, such as liquor ammoniæ. The eye was dry, the iris contracted, and the winking of the eyelid was no longer observed. On the following day, the eye of the sound side was inflamed in consequence of the stimulus of the ammonia; the other eye was free from inflammation, the development of which, therefore, had been prevented by the want of sensibility. In other experiments, division of the nerve was followed, at the expiration of several days, by inflammation of the conjunctiva, secretion of purulent matter from the eyelids, iritis, and the formation of pseudo-membranes in the eye itself. Other effects that have been observed, are a softened unhealthy state of the gums, a white appearance of the tongue, and a thickening of its epithelium on the affected side.

Nervus glosso-pharyngeus.—I have shown that this nerve also has two roots, one of which has a ganglion. Its distribution corresponds with this structure. It supplies the mucous membrane of the back part of the tongue, and it also gives branches to the pharyngeal muscles, particularly to the stylo-pharyngeus; and it is proved to have motor power by the observation of Mayo, which I have since repeated in a rabbit, that the application of galvanism to the nerve, even after death, excites muscular contractions in the pharynx.

It appears, however, from the experiments of Dr. J. Reid, (*op. cit.*) that the conclusion deduced from Mr. Mayo's experiment is erroneous, and that the glosso-pharyngeal nerve is really a nerve of sensation only. Dr. Alcock, of Dublin, had found that after division of the glosso-pharyngeal nerves, the movements of deglutition were greatly impeded; but in Dr. Reid's experiments this effect was never induced, unless the pharyngeal branch of the par vagum was also divided; hence the pharyngeal branches of the glosso-pharyngeal nerve, he remarks, cannot be the sole nerve by which the impressions, or peculiar sensations that induce the motions of deglutition, are communicated to the central organs of the nervous system.

Nervus vagus cum accessorio Willisii.—At the point where the vagus passes through the foramen lacerum, its whole trunk swells into a ganglion; it thus presents every resemblance to the sensitive root of a spinal nerve; and, as immediately after its exit from the foramen it is joined by a portion of the nervus accessorius, it is in the present state of our knowledge very natural to suppose that the vagus derives the motor fibres, which are distributed in its branches to the larynx and pharynx, from the nervus accessorius. Goerres, (*Exposition der Physiologie*. Coblenz, 1805, p. 328,) indeed, had likened the origins of the vagus and spinal accessory to the two roots of spinal nerves, even before the discovery of the properties of the anterior and posterior roots of those nerves. The same idea has been more recently adopted by Professors Arnold and Scarpa, who have compared the vagus to a posterior, the spinal accessory to an anterior root; and Bischoff (*Nervi Accessorii Willisii Anatomia et Physiologia*. Heidelberg, 1832,) has adduced new arguments in support of this view.

The view which we ourselves take of the accessory and vagus nerves is this:—The vagus corresponds, for the most part, to the posterior root of a spinal nerve; but we cannot, with certainty, affirm that it is wholly sensitive, since the experiment which we have detailed, and those of Dr. Reid seem to show that its root contains motor fibres, and in some animals fasciculi of fibres of considerable size are seen to pass over the ganglion without joining it. Its composition may possibly be just the reverse of the ninth, or lingual, which is in greater part, but not wholly, a motor nerve. The accessory is probably chiefly motor, and is more analogous in structure to the anterior roots of a spinal nerve; but it evidently contains, in many cases, (perhaps in all,) sensitive fibres, derived either from its own roots, or from the posterior roots of the first and second cervical.*

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* Compare Bendz, De Connexu inter vagum et accessorium, Havn. 4. An abstract is given in Müller's Archiv. 1837. Jahresb. p. xxviii.

Dr. Reid found that when the external branch of the spinal accessory was strongly compressed between the blades of the forceps, or firmly included in a ligature, the animal gave very decided evidence of suffering pain; but he does not pretend to determine whether the sensitive filaments on which this result depends belong originally to the nerve, or whether it derives them from other nerves at the base of the cranium.

The vagus affords sensitive influence to all the parts to which it is distributed; namely, to the organs of voice and respiration, the pharynx, œsophagus, and stomach; moreover, it gives a sensitive branch, which penetrates the petrous portion of the temporal bone, to the external ear,—the ramus auricularis; and the facial nerve probably derives its sensitive endowment from its connection with this branch of the vagus within the temporal bone.

The branches of the vagus, which are motor as well as sensitive, are the pharyngeal and laryngeal. Division of the inferior laryngeal nerve, or of the vagus in the neck on both sides, paralyses incompletely the small muscles of the larynx; the voice is lost, but is regained in a few days, from the superior laryngeal nerve continuing to exert its influence. The assertion of Magendie, that the superior laryngeal nerve is distributed solely to the contractors of the glottis, and the inferior to the dilators, was not confirmed by Schlemm's dissections. The vagus has no motor influence on the stomach; neither by galvanism, nor by mechanical irritation applied to the nerve in the neck, can motions of the stomach be excited: this results from the experiments of Magendie, Mayo, and myself.

With respect to the motor and sensitive properties of the individual branches of the vagus, we learn from the experiments of Dr. Reid: 1. That the pharyngeal branch in the dog is the principal, if not the sole motor nerve of the pharynx and soft palate, and that it is most probably wholly motor; a part of its motor fibres being derived from the internal branch of the spinal accessory nerve. 2. That the inferior laryngeal nerve is the motor nerve of the larynx, irritation of it producing vigorous movements of the arytenoid cartilages; while irritation of the superior laryngeal nerve (by galvanism) gave rise to no action in any of the muscles attached to the arytenoid cartilages, but merely to contractions of the crico-thyroid muscle. Experiments on living dogs showed also that division of the recurrent nerves put an end to the motions of the glottis, but that the sensibility of the mucous membrane remained; that division of the superior laryngeal nerves left the movements of the glottis unaffected, but deprived it of its sensibility. These results agree with the anatomy of the nerves. The superior laryngeal nerve, therefore, is chiefly sensitive; the inferior, for the most part, motor. 3. Œsophageal branches. Dr. Reid found, as had been done by previous observers, that irritation of the trunk of the vagus excited motions of the œsophagus, which extended over the cardiac portion of the stomach; and that division of the vagus paralysed the movements of the œsophagus, which became distended with the food which was afterwards taken. The motions of the œsophagus, therefore, are dependent on motor fibres of the vagus, and are probably excited by impressions made upon sensitive fibres of the vagus. Dr. Reid confirms the statement, which had been denied by Dr. Marshall Hall and Mr. Broughton, that pinching the vagus nerve in the neck gives rise to pain. 4. The cardiac branches of the nerve are believed by Dr. Reid to be one, but not the sole channel through which the influence of the central organs and of mental emotions is transmitted to the heart. 5. The pulmonary branches of the vagus form the principal, but not the only, channel by which the impressions on the mucous surface of the lungs that excite respiration, are transmitted to the medulla oblongata. Dr. Reid has been unable to determine whether they contain motor fibres.

Nervus hypoglossus, lingualis, or ninth nerve.—In the ox, and some other of the Mammalia, in which Mayer has discovered that this nerve has a small posterior root with a ganglion, it belongs to the mixed nerves with double origin; but in the human subject it has merely a motor root.

That it is principally a motor nerve, the experiments of Magendie, Mayo, and myself demonstrate. (See *Froriep's Notiz.* No. 647.) Violent spasms of the whole tongue, to the tip, are excited by stretching, pinching, or by galvanising it even with a single pair of plates. Its division in a living animal deprives the tongue of its power of motion. This nerve, therefore, supplies the motor influence for the motions of the tongue in deglutition and articulation.

The hypoglossal is also the motor nerve of the large muscles which move the larynx.

Desmoulins, Magendie, and Mayo assert, that the hypoglossal nerve is likewise endued with sensibility; pain is produced, they say, by stretching it in dogs and cats. In dogs, this sensibility might be supplied by its small posterior root; and in the cat, where Mayer has found no posterior root, it may be due to sensitive fibres received from other nerves in its course, for instance, from its connections with the nervus vagus, and with the first cervical nerve.

Nerves, for the most part motor, and without a ganglion on their root, but which contain within themselves sensitive fibres, or receive them in their course from other nerves.

Nerves of the muscles of the orbit. The third, fourth, and sixth.—These nerves have some sensitive endowment. The sensibility which muscles generally possess, can in other instances be ascribed to the sensitive fibres derived from the posterior roots of the nerves, and distributed with the motor fibres to the muscles. But this explanation is inapplicable in the case of the muscles of the eye. It is known to every one, that violent action of these muscles is attended with the sensation of an unpleasant tension in them. Is this owing to the single motor non-gangliated roots of the nerves of these muscles containing sensitive fibres? or do the nerves receive sensitive fibres from other sources in their course? The nervus trochlearis has been frequently seen to be connected with the first division of the fifth; I have myself seen, in the calf, a twig given off to the trochlearis from the latter nerve. It is not known whether the sensitive fibres of the longer root, which the ciliary ganglion derives from the nasal branch of the fifth, are all distributed in the ciliary nerves; or whether some reach the short root of the ganglion, and thus the motor oculi nerve. The sixth, or abducens, nerve can apparently derive no sensitive fibres from other nerves. Under these circumstances it must remain undecided whence these nerves acquire the fibres by which they are endued with sensitive power.

Nervus facialis, or portio dura of the seventh nerve.—This is the special motor nerve of all the muscles of the face (the muscles of mastication excepted), of the occipito-frontalis, the muscle of the ear, the stylohyoid muscle, the posterior belly of the digastricus, and the platysma myoides. Division of the facial nerve in Mammalia paralyses all the muscles of the face: the eyebrows cannot be raised, nor the eyes closed; the muscles of the ear do not act, and the nostrils are motionless, &c. Experiments which establish this have been instituted by Bell, Mayo, Schoeps, Backer, myself, and others. Backer remarked, in an animal poisoned with nux vomica, that division of the facial nerve put a stop immediately to the spasms in the muscles of the face, although they continued in other parts of the body.

Sir C. Bell regarded the facial nerve as motor only, but it is also highly sensitive. M. Magendie has stated (Comptes Rendus, 1839, Juin 3), that the middle branch only of the facial nerve is in the rabbit endowed with sensibility, and he has described the filament of the fifth nerve to which this is due.

The sensibility of the nerve is undubitable; but whether its sensitive fibres are contained in the nerve itself from its origin, or superadded to it in its numerous anastomoses with the fifth nerve, namely, with the superficial temporal, subcutaneous malæ, infra-orbital, and mental branches, in another question.

We must admit that the facial nerve is at its origin simply motor, or that it receives sensitive fibres from the brain without having a special sensitive root. The last supposition, however, is not necessary; for the source can be distinctly shown from which the facial nerve derives the sensibility which it still retains at its exit from the stylo-mastoid foramen when the trunk of the nervus trigeminus is divided. A branch of the vagus, namely, unites with the facial nerve in its course through the Fallopian aqueduct. This communicating branch, which exists in man as well as in animals, and which completely explains all difficulties, was first discovered in the human subject by Comparetti, and has also been described by Cuvier in the calf. It is given off from the nervus vagus at an acute angle, and passes through a special bony canal to reach the facial nerve, with which a portion of its filaments unites; while the continuation of the branch is distributed to the external ear. This nerve, which we have seen in the calf as well as in the human subject, is evidently a principal cause of the sensibility of the facial nerve. For further information on the subject of this chapter, see Chapter II. of the 4th Section of this Book.

CHAPTER III.

OF THE SENSITIVE AND MOTOR PROPERTIES OF THE GANGLIONIC NERVES.

1. *The ganglionic nerves are sensitive.*—Some observers have denied to the sympathetic the property of conveying sensations. Bichât states, that he irritated the cœliac ganglion both mechanically and by chemical stimuli without exciting pain. Dupuy cut out the inferior cervical ganglion, and the animals, he says, did not suffer. Wutzer also could excite no pain by irritating the lumbar ganglia in a dog. The observations of Magendie and Lobstein agree with the foregoing. Flourens, on the contrary, has in such experiments always observed more or less distinct signs of pain. In Brachet's experiments there were sometimes manifestations of suffering, sometimes none. Mayer has observed, that both when the superior cervical ganglion was divided, and when the solar plexus was irritated, the animals gave distinct evidences of pain. With these last observers, my experiments lead me to agree entirely. I have not only several times seen distinct signs of suffering produced by the application of mechanical and chemical irritants to the cœliac ganglion, but, in all experiments of tying the nerves of the kidneys which I performed in conjunction with Dr. Peiper, I observed evident signs of considerable pain. The painful sensations felt in diseased states of the parts supplied with sympathetic nerves only, prove, much more clearly than experiments can do, that these nerves have sensitive endowments. I must give my complete assent to the following remark of Prof. E. H. Weber:—"I, for my part, regard the daily observations of the existence of pain in these parts, which some would deny to be sensible, as far more worthy of attention than the foregoing experiments."

The sensibility of the parts supplied by the sympathetic is, however, far more feeble and indistinct than in other parts; for we seldom feel in the stomach the very cold or hot food which we swallow; substances, too, which are strong stimulants of the skin, such as mustard and horseradish, are rarely productive of sensation in the parts furnished with sympathetic nerves; it requires very strong impressions to excite the whole sensitive power of these parts in as powerful a degree as can be done in other organs. This peculiarity has been explained on the hypothesis of Reil, that the ganglia have the nature of half-conductors, preventing the transmission of weak impressions, and allowing the transmission of such only as are the effects of very intense irritation.

2. *The ganglionic nerves have a motor, though involuntary influence on the parts whcih they supply.*—The experiments which I

performed with Dr. Sticker have proved that the contractile power of the muscles is the result of a reciprocal action between them and the nerves, and is lost, like the excitability of the nerves themselves, in a short period after their division, if reunion do not take place; it is evident, therefore, that the contractions of the involuntary muscles also must be under the influence of their nerves, and cannot be a property of themselves as muscles, as Haller supposed. We have, likewise, some direct proofs of the motor influence of the ganglionic nerves on the muscles. Humboldt has excited contractions of the heart in Mammalia, by the application of galvanism to the cardiac nerves; and since his experiments were formed with the simple galvanic circle, they are certainly of great weight. A satisfactory proof of the motor power of the sympathetic is the experiment which I have frequently instituted, and constantly with the same result, on the cœliac ganglion in the rabbit. The abdomen of a rabbit being opened, I waited until the active motions of the intestines excited by the influence of the atmosphere had subsided, or ceased, and then touched the cœliac ganglion with caustic potash, when the peristaltic motions were immediately renewed with extraordinary activity.

Motor and sensitive fibres in the sympathetic nerves.—The question now presents itself, whether there are in the ganglionic nerves fibres of one kind only, and whether these perform all the functions of nutrition, sensation, and motion; exciting sensations by their action on the brain, and nutrition and motion by an influence transmitted in the peripheral direction. This is in itself improbable; for, were it the case, the excitement of secretion in the intestinal canal would always be attended with increased motion, and increased motion with increased secretion. This consideration is alone sufficient to suggest the probability that even in the ganglionic nerves there are sensitive and motor fibres; and, moreover, a third kind of filaments, organic fibres, namely, for the regulation of the chemical processes. To determine this question with greater certainty, we must more accurately consider the connection which exists between the sympathetic and the sensitive and motor nerves.

The relation of the sympathetic with the cerebral nerves is very complicated, while its connection with the spinal nerves is simple and easily made out. The investigation of its communications with the latter nerves affords us principles by which the nature of its connections with the cerebral nerves may be determined. It can be seen without difficulty, in any animal, that from the roots of every spinal nerve a portion is given off to join the ganglionic nerves. This forms the ramus communicans. Its fibres run, for the most part, *from* the spinal nerves *to* the ganglionic nerve.

But do these roots supply the ganglionic or sympathetic nerve with both motor and sensitive fibres from the spinal cord and brain? Scarpa and Wutzer inferred, from their earlier researches, that the sympathetic is connected with both roots of each spinal nerve, and consequently receives both sensitive and motor fibres, which the functions of the viscera dependent on its influence show that it must contain. The investigations of myself, of Retzius, Mayer, and Wutzer, have established as correct the view which Wutzer had formerly taken, namely, that the sympathetic derives radicle fibres from both roots of the spinal nerves. Mayer has indeed traced these fibres in the roots of the nerves as far as the spinal cord itself. The sympathetic contains, therefore, both motor and sensitive fibres.

By the microscopic examination of the radicle fasciculi derived by the ganglionic nerve from the spinal nerves, it is learnt that they consist of cylindrical fibres, similar to those which compose the spinal nerves themselves: the tube and its contents are as easily distinguished. The peculiarity of the sympathetic seems to consist merely in the mode in which it assembles its radicle fibres, and again distributes them in the peripheral direction. The radicle fibres run, namely, for a certain extent in the principal cord of the sympathetic before being given off in the branches; and thus is produced an apparently continuous cord from the superior cervical ganglion to the ganglion coccygeum. I say, apparently continuous; for there are no facts to justify the conclusion that the fibres coming from the first cervical ganglion are continued to the inferior extremity of the cord. The fibres leave the longitudinal cord in the same order as they enter it: the first form the cardiac nerves, the next the splanchnic, the next the renal, the aortic, and so on. This relation of the fibres to the principal cord of the sympathetic, may be compared to the mode of attachment of the sacro-lumbalis muscle to the ribs. But it is not really a peculiarity of the sympathetic. It is a structure common to many other nerves; the spinal nerves, for example, have arches of communication between each other, and thus form continuous cords, extending a considerable distance, from which are given off in succession the nerves which had previously joined them. The nerve called the *ramus descendens noni*, again, is partly formed by the superior spinal nerves. On the other hand, it sometimes happens that the cord of the sympathetic is interrupted here and there between the points where the radicle fibres join it, or is extremely thin, as in serpents.

It being shown that the sympathetic regularly receives fasciculi of motor and sensitive fibres from the spinal nerves as its motor and sensitive roots, the existence of a similar relation between it and those cerebral nerves which are analogous to the spinal nerves, in having double roots, becomes very probable. The hypoglossal, vagus, and glosso-pharyngeal nerves do in fact give roots to the superior cervical ganglion, and thus to the cord of the sympathetic. We do not, however, mean to assert that all the fibres of these cords are motor and sensitive, for such is not the case. The ganglionic or sympathetic nerve, then, receives roots of sensitive and motor properties from the cerebral nerves which we have named. It likewise receives a similar root from the great spinal nerve of the head, the nervus trigeminus. The vidian nerve is, at least in part, a root given off to the sympathetic, as will be more distinctly proved in the following Chapter. An account of some recent observations by Valentin relative to the origins of the motor and sensitive fibres of the sympathetic will be given in Chapter V. of the following Section.

CHAPTER IV.

OF THE SYSTEM OF GREY OR ORGANIC FIBRES, AND ITS PROPERTIES.

In the present state of our knowledge, little instruction can be derived from the views of the earlier physiologists relative to the properties of the sympathetic or ganglionic nerves. It is not sufficient to be told that these nerves are destined for the supply of the vegetative system of the viscera, while the cerebro-spinal nerves supply the animal system;—that they have the office of uniting the nerves, one with another, into one harmonious whole;—or, that they are the cause of the sympathies. The important labours of Sir C. Bell, relative to the sensitive and motor roots of the nerves, left us in ignorance concerning the sympathetic; but they suggested to intelligent minds the necessity of a complete reform of our notions regarding this nerve. It is but recently that the facts and ideas contributing to this reform have been published.

On this subject I founded my opinions on the observations of Retzius and on my own investigations relative to the presence of organic grey fibres running in the peripheral direction in the cerebral nerves—on the fact of the primitive fibres of nerves not uniting with each other in their course—on the origin of the ganglionic nerve from the motor and sensitive roots of the spinal nerves—and on the facts relative to the reflex actions of the nervous system. I expressed* my conviction, not merely that the commonly received notions respecting the supposed use of the connections of the ganglionic with other nerves,—namely, the transmission of sympathetic influences,—are erroneous; but that the ganglionic, as well as the cerebro-spinal nerves, are compound in structure. I suggested that they contain motor, sensitive, and organic fibres, of which the latter kind alone have the function of regulating the vegetative processes, and have a special relation to the ganglia; that the cerebro-spinal nerves are likewise composed of motor, sensitive, and organic fibres, of which those of each kind have their specific destination, and run their course together without uniting with the others; that the ganglionic nerve consequently differs only in having numerous ganglia, and in containing a large number of grey fibres, which give it a proportionally greyer colour; while, in the cerebro-spinal system, the grey fibres are less numerous, and are seen as grey fasciculi lying in the larger mass of white fibres. The ganglionic nerve is not, however, I observed, equally grey in all parts; the main lateral cords are whitish; the branches of the abdominal ganglia, which are distributed to the viscera of vegetative life, principally grey. This is the history of the progress of our knowledge of this subject up to the present time. Remak has brought it to a state of far greater certainty.

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* In the second part of the first volume of the Handbuch der Physiologie, published in 1834; p. 646—652, and p. 780.

1. *Grey or organic fibres in the cerebro-spinal nerves.*—The facts relative to this subject, which were given in the first edition of this work, are the following:—First, the remarkable and important observation of Retzius (*Isis*, 1827, p. 997), that in the nervus trigeminus of the horse, and particularly in its second division, there are distinct grey sympathetic fibres, derived from the spheno-palatine ganglion, which form small grey ganglia in their course, and can be traced upon the surface, and within the substance of the second division of the nerve, as far as the nasal branches and the pituitary membrane, as well as upwards into the orbit and to the ciliary ganglion.

In the human subject, too, fibrils have been seen by Varrentrapp[*] to be given off from the cavernous plexus to the first division of the nervus trigeminus. Moreover, in the calf, I have seen a thick fasciculus of organic fibres, sent from the sympathetic within the cranium to join the second division of the fifth nerve, just below the Gasserian ganglion.

Several new facts have been made known by M. Giltay (*De nervo sympathico Diss.* Lugd. 1834), showing that organic fibres can be traced accompanying cerebral and spinal nerves as far as the organs to which they are distributed.

From a variety of facts, but which are denied by Valentin, I arrived at the conclusion, that in the cerebro-spinal nerves three kinds of fibres must be distinguished; the sensitive and motor, both of which are white, and come from the roots of the cerebro-spinal nerves,—and grey organic fibres, which have their origin in the ganglia of the ganglionic or sympathetic nerve itself.

The observations of Remak, also disputed on the ground of inaccuracy by Valentin, have made us acquainted with the peculiar microscopic characters of the grey fibres, by which they may be distinguished from the tubular, sensitive, and motor fibres. They are, namely, much more minute; they are perfectly homogeneous, that is to say, not composed, as far as can be distinguished with the microscope, of a tube and contained portion; and are so pale and transparent, that in a strong light they are not visible; lastly, a completely characteristic appearance is produced by the small roundish or oval bodies which here and there beset their surface.

All the grey nervous fasciculi which we have described as accompanying in their peripheral distribution the first and second division of the fifth nerve, are composed of such fibres. The grey fibres are also contained in the grey fasciculi, which, coming from the otic ganglion, or plexus gangliiformis Santorini, accompany the third division of the fifth nerve, and particularly the buccinator branch.

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[*] Obs. anat. de parte cephalicâ n. sympathici. Francof. 1831.

In the difference of microscopic character between the sensitive and motor and the organic fibres, an excellent means is afforded us of ascertaining how far the branches of communication between the cerebro-spinal and ganglionic nerves belong to the one system or to the other. Many nerves, which were formerly regarded as wholly sympathetic, are thus found to be in part of the nature of cerebro-spinal nerves.

2. *Grey or organic fibres in the ganglionic or sympathetic nerves.*—In the former edition of this work the existence of two kinds of fibres in the sympathetic nerve also could only be shown to be probable, it could not then be satisfactorily proved. It was even then suggested, however, that the ganglia of the sympathetic belong to its organic fibres. Remak has by minute examination been able to distinguish even externally in many parts of the sympathetic nerve grey and white fasciculi: and the microscope has in every instance revealed to him tubular fibres in the latter, and the peculiar organic fibres in the former kind of fasciculi. The results of his long and patient investigation render it very probable also that the organic fibres arise from the globular bodies in the ganglia, and from the caudal prolongations of these bodies; he regards it indeed as a fact, that they do arise thus, for he has very frequently seen coming off from the globules of the ganglia filaments beset with granules similar to those observed on the organic fibres. The accuracy of these observations is denied, however, by Valentin.

The mere existence of distinct sensitive and motor fibres would, *à priori*, lead us to expect that there should be other special fibres to rule over the vegetative processes of the body. The nerves have a most marked influence on secretions, and, if there were but one kind of nerves for the regulation of the movements and the chemical processes, the increase of a secretion by nervous influence ought to be always attended with spasm, and spasm with increased secretion; while the two phenomena are often met with separately, just as paralysis of the motor power occurs without loss of sensation, and paralysis of sensation without loss of motion. If, moreover, we consider how frequently the grey fibres join the trigeminus, abducens, and facial nerves, in the first of which they can be traced distinctly in their course towards the mucous membranes of the mouth and nose; if we recollect that in the tympanum there is a plexus, formed principally of organic filaments, destined for the supply of the mucous membrane; and that no involuntary motions are performed by the mucous membranes, or even by the parts to which the second division of the fifth nerve and the nervus abducens are distributed; we shall at once perceive the much greater probability of the second opinion—namely, that the organic fibres in the cerebro-spinal, as well as in the ganglionic nerves, have the function of regulating the organic processes of nutrition and secretion. This view is much favoured, too, by the fact that the sympathetic receives from the motor roots of the spinal nerves motor tubular fibres, on which the involuntary motions must be dependent. If this be really the function of the organic fibres, the motor nerves of the heart ought to consist principally of the white tubular fibres. And such is in fact the case. Microscopic examination of the cardiac nerves of the calf shows them to contain a great number of tubular fibres, which differ from the nervous fibres distributed to voluntary muscles merely in having a smaller diameter; and, if we compare the cardiac nerves with the splanchnic nerves which supply the secreting viscera, the much greater tendency to the formation of ganglia in the latter nerves will strikingly distinguish them from the former. The cardiac nerves develope no central ganglia, the splanchnic swell out to form the great cœliac ganglion. There is the same difference between the nerves of the heart and those of the generative organs supplied from the hypogastric plexus. Those, too, which accompany the renal vessels to the kidneys, are composed in by far the greater part of grey organic fibres. The organic nerves of the penis, which I have described as entering the corpora cavernosa at their root, and on which erection is dependent, are grey.

In many cases the organic fibres appear to be wholly interwoven with the cerebro-spinal nerves. In this way we might explain the absence of a proper sympathetic nerve in the cyclostomatous fishes (in the petromyzon as well as in the myxinoidea): the nervus intestinalis formed by the two nervi vagi runs, in the myxinoid fishes, along the line of insertion of the mesentery as far as the anus. And on this supposition only can we explain the fact, that in the human mammary gland there are, according to my observation, no special organic nerves. All the nerves of the glandular substance of the mamma are derived from the third and fourth intercostal nerves.

SECTION III.

OF THE MODE OF PROPAGATION OF NERVOUS ACTION IN THE DIFFERENT NERVES.

It is yet uncertain whether nervous action, which is propagated with such immeasurable rapidity, is owing to the passage of an imponderable matter along the nerves,—whether the action of a nerve separated from the nervous centres when irritated, is owing to a current of such imponderable matter taking place through it; or whether nervous action consists merely in oscillations or vibrations excited by the brain or the external stimulus, in an imponderable nervous principle present in the nerves; and it is a problem at present as little capable of solution as the same question with reference to light, namely, whether the theory of emanation or that of undulation of light is correct. But the decision of this difficulty is no more necessary to the study of the laws of nervous action, than is the knowledge of the true theory of light necessary for ascertaining the laws of its reflection, refraction, &c.

In comparing the different parts of the nervous system, we find conductors and excitors of nervous action. The conductors are the nerves; the excitors, the central organs. The nerves, however, have not merely the quality of conductors; for, after separation from the brain, they are for a certain time capable of exciting, when irritated, contractions of the muscles; but, after they are thus cut off from communication with the central organs, they gradually lose this faculty. Regarding the nerves as conductors, the propagation as well as the action of the nervous principle may be explained by either of the theories above mentioned. Either the imponderable fluid is transmitted in a certain direction through the nerves as a current, or there is merely an oscillation excited in this fluid within the nervous fibres. The rapidity of nervous action, again, may depend either upon the rapidity of the transmission of the nervous fluid between the brain and the peripheral parts, or on the velocity with which a vibration commencing at the brain or any given point of a nerve, is propagated to its peripheral extremity, or *vice versâ*.

The attempts made to estimate the velocity of nervous action have not been founded on sound experimental principles. Haller calculated that the nervous fluid moves with the velocity of 9000 feet in a minute; Sauvages estimated the rate of its motion at 32,400, and another physiologist, at 57,600 million feet in a second. (See *Haller's Elementa*, t. iv. p. 572.) Whilst the galvanic principle and the nervous principle were regarded as identical, the rate at which the latter acts was calculated from the rapidity with which electricity is transmitted through conductors. We shall probably never attain the power of measuring the velocity of nervous action; for we have not the opportunity of comparing its propagation through immense space, as we have in the case of light.

The time required for the propagation of a sensation from the surface to the brain and spinal marrow, and for the reflected action producing contractions of the muscles, is immeasurably short. Frogs poisoned with opium or nux vomica are, at first, in a state of such excessive sensibility, that the slightest touch on the skin excites convulsions of the whole body. Here the impression made on the skin is propagated first to the spinal cord, and from the cord to all the muscles; and, nevertheless, I have been unable to detect the slightest interval between the moment when the skin was touched and the occurrence of the muscular spasms.

CHAPTER I.

OF THE LAWS OF THE ACTION OF MOTOR NERVES.

a. *Of the laws of the transmission of nervous influence in motor nerves.*

I. *The motor influence is propagated only in the direction of the nervous fibres going to the muscles, or in the direction of the ramification of the nerve; and never in a retrograde course.*—It is a fact generally known, that by irritation of a motor nerve, contractions are excited in no other muscles than those to which the nerve distributes branches. When a nerve is irritated, either by chemical, mechanical, or electric stimuli, or by the application of both poles of a galvanic circle to the nerve itself, all the muscles supplied by the branches given off by the nerve below the point irritated are thrown into contractions, and those muscles only. The muscles supplied by the branches which come off from the nerve at a higher point than that to which the stimuli are applied, are never excited to contractions. Not the slightest twitchings are ever produced in the muscles of the thigh by irritating the lower part of the ischiadic nerve.

II. *The application of mechanical or galvanic irritation to a part of the fibres of a nerve does not affect the motor power of the whole trunk, but only that of the insulated portion to which the stimulus is applied.*—This experiment can be best performed on rabbits, on account of the larger size of the nerves in them than in frogs. The ischiadic nerve being laid bare where it issues from the pelvis, different portions of it, which afterwards separate from the trunk as branches, may be easily irritated individually with a needle; and it will be satisfactorily seen, that those muscles only are thrown into contractions to which the irritated portion is ultimately distributed. To be able to see the slightest twitchings of the muscles, the skin must be removed from the whole limb as far as the foot.

III. *A spinal nerve entering a plexus, and contributing with other nerves to the formation of a great nervous trunk, does not impart its motor power to the whole trunk, but only to the fibres which form its continuation in the branches of that trunk.*—This is shown by experiments of Van Deen, myself, and Kronenberg.

Facts are every day observed which confirm the above remarks, and show that, although the same nerves frequently give branches to many different muscles, the cerebral influence can nevertheless be limited to particular branches or single fasciculi of a nervous trunk. The nervous influence transmitted from the brain, for example, in diseases of that organ, is frequently confined to most minute portions of muscles, which then are affected with tremors. Moreover, we know that the primitive fibres of the nerves are anatomically distinct; so that, taking into consideration both the anatomical and physiological facts, we are justified in the conclusion that even the individual primitive fibres in the nerves and their branches maintain their motor power insulated within themselves.

b. Of the associate or consensual movements.

I here refer to those movements which, contrary to our will, accompany other, voluntary, motions. Several of these phenomena were formerly confounded with others of a different nature. Examples of the true consensual movements are very frequent, even in the healthy state of the body. When we endeavour to contract the muscles of the external ear, we induce motion of the occipito-frontalis muscle also, and of several muscles of the face. When we wish to elevate and depress the alæ nasi, we corrogate at the same time, without willing it, the eyebrows. Very few persons indeed can cause the different muscles of the face to act singly; they cannot in most instances make the individual muscles act, except in groups with other muscles. The perineal muscles, the sphincter ani, levator ani, transversus perinæi, accelerator urinæ, and compressor urethræ, nearly always act simultaneously when volition is directed to one only. This association of movements is most striking in the case of the iris. [We cannot move the eye inwards by the action of the rectus internus, without contraction of the iris being produced.] The iris contracts likewise whenever the eye is turned upwards and inwards by the action of the obliquus inferior. The motor influence both for the two muscles here named and for the iris is derived from the same nerve, namely, the nervus motorius oculi, which supplies the short motor root to the ciliary ganglion. When, therefore, the influence of volition is directed upon the motorius oculi nerve, or rather upon those of its fibres which supply the muscles in question, the nervous stimulus is always communicated in a certain degree to other primitive fibres of the nerve,—to those, namely, which form the short root of the ciliary ganglion.

Similar phenomena are indeed observed in all parts of the body. Most persons find a difficulty in calling into action separately the individual portions of the musculus extensor com. digitorum, so as to extend singly separate fingers; for example, the third or fourth, which have no special extensor muscles. During violent bodily exertion many muscles act by association, although their action serves no apparent purpose; a man using great muscular exertion moves the muscles of his face, as if they were aiding him in raising his load; during laboured respiration, and in persons in a state of debility, the muscles of the face act simultaneously but involuntarily; although, except by raising the alæ nasi, they can in no way assist respiration. The phenomena of this kind are so numerous, so frequent, and so constantly the same, that the few examples which we have cited will be sufficient. I must, however, mention one fact as worthy of special attention, since it is the most complete example of the tendency to consent of muscular action between similar parts of the right and left side of the body. It is the involuntary motion of the iris. The motion of the iris is always simultaneous in the two eyes, as well when it is excited by an external stimulus, as when it is the effect of volition: even when the stimulus, be it external or internal, acts on one eye only, both irides contract equally. If but one eye be opened, the contraction of the pupils will be less than when an equal impression of light falls upon both eyes. If the impression of light on the two eyes be unequal, the size of the pupil in the two will still be equal; but it will be the mean between those which the two different impressions of light would produce. The same law prevails when the motions of the iris are determined by internal volition. We can at any time voluntarily excite consensual motion of the iris, as I have already stated, by rotating the eye inwards, or inwards and upwards; but the most remarkable circumstance is, that the irides of both eyes contract when one eye only is turned inwards, the other being still directed forwards. The power which every one has of contracting the iris by turning inwards the eye, I possess in an extraordinary degree. If I cover one eye, A, and look directly forwards with the other eye, B, I can move the iris of this eye, which I keep fixed, at will, contracting it or dilating it according as I rotate the covered eye, A, inwards or outwards. In this experiment, the cause of the motion of the iris is concealed, and the motions are the more striking from the eye in which it is seen to take place being fixed. The cause, however, is immediately evident when I open the eye, A; it is then perceived that to produce a contraction of the iris in the fixed eye, B, I always rotate inwards the other eye, A. It is obvious that there must be a certain arrangement of the fibres in the brain, which gives rise to the tendency to association in action of those fibres of the two motores oculi which go to form the ciliary nerves. An interesting fact, easily explicable according to the principles here laid down, is the contracted state of both irides in sleep. It is a consensual motion dependent on the position of the eyes, which are turned upwards and inwards by the inferior oblique muscles. Many other muscles of the two sides of the body, besides the irides, have a tendency to association in their movements. Thus the muscles of the eyes have this tendency; it is impossible, for example, to turn one eye downwards, the other outwards, or both outwards at the same time. When one eye is turned outwards, the other is always rotated involuntarily inwards. It requires practice to be able to keep one eye open while the other is shut; that is to say, to contract the levator palpebræ of one side only by the influence of the motor oculi nerve. Few persons have the power of moving, by the influence of the facial nerve, the muscles of one side of the face differently from those of the other side. I can move the muscles of the ear, even the smaller ear-muscles, the anti-tragicus at least, quite distinctly; but when I determine voluntarily these motions in one ear, they always take place on the other side also. I do not know whether it is possible to cause the musculus stylo-hyoideus of one side to contract alone. There is a similar tendency to consentaneous motion between the corresponding muscles of the two sides of the trunk, but it is much less marked: the abdominal and perineal muscles, and the diaphragm, nearly constantly act simultaneously on the two sides; and even the nerves and muscles of the extremities, although they are more independent in this respect, are not wholly exempt from the general law. The difficulty of executing simultaneously with the two upper or the two lower extremities, rotatory motions in opposite directions, for example, around a common axis, is well known; while similar motions with both extremities are much more easily performed.

The explanation of all these phenomena is evident. The primitive fibres of all the voluntary nerves being at their central extremity spread out in the brain to receive the influence of the will, we may compare them, as they lie side by side in the organ of the mind, to the keys of a pianoforte, on which our thoughts play or strike, and thus give rise to currents or vibrations of the nervous principle in a certain number of primitive nervous fibres, and consequently to motions. From the conducting power of the cerebral substance at the origin of the nervous fibres, however, those which are contiguous to each other must be liable to be affected simultaneously, and the influence of volition will with difficulty be confined to single fibres. The faculty of insulating the influence of the will is, however, acquired by repeated exercise; that is to say, the more frequently a certain number of nervous fibres are exposed to the influence of volition, the more prone do they become to obey it independently of other surrounding fibres; or, in other words, certain paths for the more ready transmission of the cerebral influence are gradually developed. This faculty of insulation of the influence of volition is seen to reach the highest degree of perfection in certain arts, for example, in the use of musical instruments, particularly of the pianoforte.

All associate movements have their source in the brain itself; they cannot be attributed to a communication between the primitive fibres in the motor nerves; for, in the first place, the primitive fibres do not communicate with each other; and, secondly, irritation of a portion only of a great nervous trunk never influences the rest of the nerve, but is propagated only to those branches of it which are formed of the fibres irritated.

The associate movements cannot, moreover, be ascribed to the action of the sympathetic nerve, which maintains communications neither between different portions of a motor nerve, nor between the corresponding nerves of the two sides of the body; such communications are effected solely by the brain and spinal cord. ✓

CHAPTER II.

OF THE LAWS OF THE ACTION OF SENSITIVE NERVES.

a. Of the law of the propagation of the nervous influence in the sensitive nerves.

A NERVE preserves its sensitive power only so long as it maintains its communication with the sensorium, either directly, or indirectly through the medium of the spinal cord. We will now consider here, as in the case of the motor nerves, the relation which subsists between the trunks and branches.

I. *When the trunk of a nerve is irritated, the sensation is felt in all the parts which receive branches from it; the effect is the same as if all the ultimate ramuscules had been irritated.*—If one branch only of a nerve is irritated, the sensation produced is confined to the part to which that branch is distributed: if the irritation is applied to the trunk itself, the sensation is felt in all the parts to which the nerve sends branches. These experiments can of course be instituted only in one's own person; but the results they afford are as certain as those of the experiments on motor nerves in animals. If we stretch or pinch the ulnar nerve intentionally, by pushing it from side to side, or by compressing it with the fingers, where it lies at the inner side of the elbow-joint above the internal condyle, we have the sensation of "pins and needles," or of a shock, in the parts to which its ultimate ramuscules are distributed; namely, in the palm and back of the hand, and in the fourth and fifth finger. If stronger pressure is made, the sensations are felt in the fore-arm also. By drawing the thumb up and down, at the same time exerting pressure along the inner side of the upper arm, and by pressing deeply quite at the upper part of the arm at the inner side, we may easily reach the median and radial nerves, and excite similar sensations in the parts to which they are distributed. Pressure on the main nervous trunk of a limb —for example, on the nervous ischiadicus,—produces the well-known sensation of pins and needles in the whole limb, or the sensation of the limb being "asleep." By a particular position of the thigh in the sitting posture, the ischiadic nerve may be compressed at its very exit from the pelvis. Having ascertained the situations where other, even small nerves, can be subjected to such mechanical irritation, we may in this way institute experiments in our own person analogous to those performed on animals with reference to the motor function.

II. *The sensation produced by irritation of a branch of a nerve, is confined to the parts to which that branch is distributed, and generally, at least, does not affect the branches which come off from the nerve higher up, or from the same plexus.*—The facts by which this is proved are so well known that it is unnecessary to detail them singly. Irritation of the skin is ordinarily felt only in the spot where the irritant is applied. The irritation never reacts, for example, upon the brachial plexus, and on the other nerves which arise from it.

III. *When, in a part of the body which receives two nerves of similar function, one is paralysed, the other is inadequate to maintain the sensibility of the entire part; on the contrary, the extent to which the sensibility is preserved corresponds to the number of the primitive fibres unaffected by the lesion.*—When two nerves anastomose, they have not the power of compensating for the inactivity of each other, as is the case when two arteries anastomose; wherever two cerebro-spinal nerves unite to form a thicker trunk, the paralysis of one root of this trunk deprives of their power all the primitive fibres derived from that root. Thus, when the ulnar nerve, which supplies the fourth and fifth fingers and a part of the third, is divided, the sensibility of those parts is not supplied through the medium of the anastomoses of the ulnar with the median nerve; but the fourth and fifth fingers are permanently deprived of sensibility. If the outer side of the fourth finger retains a slight degree of sensibility, it must be due to the primitive fibres of the median nerve which join the volar branch of the ulnar.

IV. *When different parts of the thickness of the same nerve are separately subjected to irritation, the same sensations are produced as if the different terminal branches of these parts of the nerve had been irritated.*—If the ulnar nerve be irritated mechanically in the manner already described, particularly by pressing it from side to side with the finger, the sensation of pins and needles is produced in the palm and back of the hand, and in the fourth and fifth finger. But, according as the pressure is varied, the pricking sensation is felt by turns in the fourth finger, in the fifth, in the palm of the hand, or in the back of the hand; and, both on the palm and on the back of the hand, the situation of the pricking sensation is different according as the pressure on the nerve is varied, that is to say, according as different fibres or fasciculi of fibres are more pressed upon than others.

V. *The sensations excited in the minute elementary fibres are transmitted from the surface to the brain, without being communicated to the other fibrils of the same nervous trunk.*—This is a necessary inference from the facts and laws already detailed.

a. Irritation of the trunk of a nerve produces the same sensation as if all the primitive fibres distributed to the peripheral parts were irritated; and the sensation is felt in those peripheral parts, just as if the irritation had been there applied to the fibres.

b. When different primitive fibres composing a nerve are irritated separately, the sensations are felt in different points of the periphery of the body.

c. Irritation of the branch of the nerve is attended with sensation in the parts to which that branch is distributed.

It would appear, therefore, to be a matter of indifference whether the stimulus be applied to the primitive fibres, where they are assembled in the nervous trunk; in the branches, where they are distributed in fasciculi; or in the peripheral parts, where they are isolated from each other. The same sensations as are produced by pricking the skin with needles, or by the creeping of ants over it, are also excited by exerting pressure on the primitive fibres where they lie aggregated in a small twig of a nerve going to a finger, in which case the sensations are confined to the skin of the finger; or by pressure on the trunk of the nerve when they are felt in the skin of all the parts which the nerve supplies.

Since each primitive fibre, in its whole length, from the brain to the skin, is in connection with the brain by one point only, namely, by its extremity, it would be expected that at whatever part it is affected, whether at its peripheral extremity, in the middle of its course, or in the nervous trunk, the same sensation must be produced; for all the impressions made upon the primitive fibre, in its whole length, can be communicated but to one point of the brain. The primitive fibres of a nerve, whether long or short, would appear, therefore, to represent each but one point in the brain, which makes us conscious of the same sensation at whatever part of its course the primitive fibre may have been irritated. The reason why the sensation appears to have its seat always in the skin, at whatever point of their length the nervous fibres are irritated, seems to be, that the sensations are ordinarily produced by an action on the skin, or on the cutaneous extremities of the fibres. Although, however, these are just conclusions from the observations we have detailed, still, the following facts show that the theory of sensations here given, is far from being completely established.

VI. *Although pressure on a nerve gives rise to sensations which are felt in the peripheral parts, yet a stronger pressure produces pain in the nerve itself at the point to which it is applied.*—We experience this but rarely, as when we suffer violent blows on the ulnar nerve. But the experiment may be made by pressing the ulnar nerve with gradually increased force against the bone above the internal condyle, when, in addition to the sensations excited in the parts which the nerve supplies, a pain will be produced at the seat of the pressure; not merely in the surrounding parts, but in the nerve itself. From the facts already detailed, and others that follow, this would not be expected; and there seems to be something here with which we are unacquainted, but which is important with relation to the theory of sensation. Something similar is observed in the case of the tumours of nerves, of which the characteristic symptoms are pains in all parts which the nerve supplies; and violent pains in all those parts attend the division of the nerve above the tumour, as I observed on the occasion of the division of the ulnar nerve in the upper arm, above such a tumour, by Prof. Wutzer. But the ganglion, or tumour, of the nerve is itself frequently sensitive and very painful. In cases of disease of the spinal cord, likewise, the pains are commonly felt in all the peripheral parts which lie below the point affected; but sometimes, though rarely, as in neuralgia dorsalis, there is pain along the middle line of the back.

It is to be lamented that operating surgeons have hitherto neglected the excellent opportunities they enjoy of observing the phenomena which attend the division of nerves.

The direction which the pain takes in cases of neuralgia, namely, along the course of the nerves, appears, likewise, not to agree with the theory of sensations above proposed. It must, however, be remarked that neuralgic pains by no means constantly follow the course of the nerves. I have examined several cases of true neuralgia in Berlin, in which the pain did not pursue the course of the anatomical distribution of the nerves.

We are are in want of information calculated to elucidate these apparent contradictions. The following facts are favourable to our theory.

VII. *When the extreme parts are completely deprived of sensibility by pressure on a nerve, or by its division, irritation of the portion of the nerve connected with the brain still excites sensations which are felt as if in the parts to which the peripheral extremities of the nerve are distributed.*—Thus there are cases of paralysis in which the limbs are totally insensible to external stimuli; but in which, nevertheless, they are the seat of most violent pain.

The innumerable cases showing that division of the nerve for neuralgic pain is generally attended with an unfavourable result, and that the pains frequently return with as great violence as before, although the nerves be divided, and even portions of them removed, afford another confirmation of the above statement. In fact, when the cause of the neuralgia is seated in the trunk of the nerve,—for example, of the facial or infra-orbital nerve,—division of it can be of no service; for the stump remaining in connection with the brain, and containing in itself all the primitive fibres distributed in the branches of the nerve to the skin, gives rise, as we know, when irritated, to the same sensations as are felt when the peripheral parts themselves are affected. It is rarely that division of the nerve, or removal of a part of it, relieves the neuralgic pain; such a result can occur only when the cause of the disease is seated in the branches, not in the trunk of the nerve.

Division of a nerve, then, merely prevents the possibility of external impressions on the cutaneous extremity of its fibres being felt; the impressions being no longer communicated to the brain. But the same sensations which were before produced by external impressions may arise from internal causes, as long as the primitive fibres of the trunk remain in connection with the brain or spinal cord.

When a nerve—of a finger, for example—is accidentally divided, the paralysed portion of the finger, although insensible to external stimuli, becomes the seat of pain, during the existence of inflammation in the wound. When the inflammation has subsided, the sense of pain ceases, and the part remains quite devoid of sensation. The observations of Gruithuisen with respect to these phenomena in his own person, which were related at page 132, are particularly interesting. Sir Everard Home (*Philos. Transact.*) relates a case in which a nerve of the face was divided for neuralgia, and where, the wound not uniting by the first intention, the inflammatory state of the divided extremities of the nerve, gave rise to attacks similar to those suffered before the operation; though, when the wound had completely healed, there was no return of the pain.

The phenomena attending the state of a limb "asleep," in consequence of pressure on the nerves, are of a similar kind. The pressure puts a stop to the nervous communication from the periphery to the brain; but the same pressure, by affecting the upper part of the nerve, gives rise to the sensation of "creeping" ("*formicatio*") and pricking in the limb, which has lost its sensibility to external impressions.

The sensation of creeping in the surface frequently attends affections even of the origins of the nerves from the spinal cord or brain, or of these latter organs themselves. When the sensation of tingling is felt in the skin, it is impossible to know whether the cause of it is seated in the skin, in the nerves themselves, or at the origin of their fibres from the spinal cord. It is frequently the spinal cord itself. In nearly all diseases of the spinal cord, tingling in the skin is a symptom; the tingling is also frequently felt in the paralysed parts which receive their nerves from the cord below the seat of the disease; in tabes dorsalis there is formicatio or tingling, not merely in the mesial line of the back, but in the skin of the whole body, or of its lower half.

√ From the foregoing remarks it will be conceived that the aura epileptica, (a kind of "*formicatio*,") which is felt in the extreme parts of the body before an attack of epilepsy, has its cause and true seat, not in those parts, but in the spinal marrow or brain. It is the first symptom of the affections of the spinal marrow and brain which show themselves during the attack. Should an epileptic fit be occasionally arrested by the application of a ligature to the limb above the seat of the aura epileptica, it must be owing, not to the ligature preventing the transmission of any morbid matter, but to its producing a strong impression on the sensorium. It must be remarked, however, that in the form of epilepsy which is dependent on tumours of the nerves, a ligature applied to the limb really arrests the propagation of the irritation to the spinal cord.

If a tourniquet is applied to the arm above the elbow-joint, the first effect is the sensation of pins and needles in all parts of the hand, then gradually numbness and the sensation of cold ensue, and at last insensibility to external stimuli. If now the nerves in the axilla and arm, above the tourniquet, are irritated mechanically by means of the fingers, the sensation of an electric shock will be felt in the hand as distinctly as when the nerves of the fore-arm and hand are not paralysed by pressure.

VIII. *When a limb has been removed by amputation, the remaining portion of the nerve which ramified in it may still be the seat of sensations, which are referred to the lost part.*—This is a fact known to all surgeons, and is subject to no exception. It is usually said that the illusion continues for some time, namely, as long as the patient is under the care of the surgeon; but the truth is, that in most cases it persists throughout life: of this it is easy to convince oneself by questioning a person whose limb has been amputated, at any period after the operation. The sensations are most vivid while the surface of the stump and the divided nerves are the seat of inflammation, and the patient then complains of severe pain felt, as if in the whole limb which has been removed. When the stump is healed, the sensations which we are accustomed to have in a sound limb are still felt; and frequently throughout life tingling, and often pains, are felt, which are referred to the parts that are lost. These sensations are not of an undefined character; the pains and tingling are distinctly referred to single toes, to the sole of the foot, to the dorsum of the foot, to the skin, &c. These important phenomena have been absurdly attributed to the action of the imagination, &c. They have been treated merely as a curiosity; but I have convinced myself of their constancy, and of their continuance throughout life,—although patients become so accustomed to the sensations that they cease to remark them. The feeling of tingling or creeping of ants in the hand, foot, or whole extremity, with the same distinctness as when the limb is still present, may be excited much more vividly by applying a ligature or tourniquet to the stump, or by exerting pressure on its nerve; hence patients have the feeling of their lost limb most distinctly, when from any cause the application of the tourniquet is again necessary. If the patient have suffered before amputation from a local painful affection of the limb, the whole limb will still be felt as if in pain after its removal; and pain will be felt as if in the whole limb, at the moment when the nerve is divided, and during the inflammation of the stump.*

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* The following are examples of these phenomena:—

a. A woman who had lost the sensibility of one arm, had the same limb fractured; mortification ensued in it, and it was amputated in the surgical clinical ward at Bonn. The amputation was not felt; but the division of the nerve must have excited its sensitive power, for in the same night the woman complained of pains, felt as if in the fingers.

b. Joh. Wolff, a journeyman tailor in Bonn, had his leg amputated at the first third of the thigh, twelve years ago. Immediately after the operation his sensations were those of his limb being still present; and, on the following day, he complained much of pains in the leg, extending to the toes. On the same day the arm was removed in another patient, and he likewise complained afterwards of pains in the hand and whole arm. Wolff I found, after the expiration of twelve years, to have still feelings which seemed to be seated in the toes and sole of the lost foot, and occasionally severe pains referable to the sole. Sometimes, from pressure in lying, the stump had the sensation of being asleep; and then, as well as frequently at other times, he felt a tingling as if in the toes. I applied a tourniquet to the stump, so as to press upon the ischiadic nerve; and he immediately said that he felt his leg asleep, and a very distinct tingling in the toes.

c. A student in surgery, a Jew, had his arm amputated above the elbow, on account of disease of the joint. As long as we had an opportunity of observing him, he could still feel the lost arm.

d. A student named Schmidts, from Aix, had his arm amputated above the elbow, thirteen years ago; he has never ceased to have sensations as if in the fingers. He imagines that he feels the hand in a bent position. He feels a pricking in the fingers, particularly when he lies upon the stump, so as to press the brachial nerves. I applied pressure to the nerves in the stump; and M. Schmidts immediately felt the whole arm, even the fingers, as if asleep.

e. My "commissionaire," during my stay in Leyden, had lost his arm by amputation above the elbow, twelve years before; but he had still occasionally the sensation of tingling, as if in the fingers, particularly when he lay upon his arm.

f. Vir quidam in nosocomio Judaico Berolinensi, cui pes sinister, et alter cui brachium sinistrum amputatum erat, dicebant ambo, alter post hebd. 14 alter 17, se per operationem nihil commodi nactos esse; alter querebatur de dolore vehementi pedis, et alter brachii, cum tamen non tam male eos habuisset quam in primis hebdomadibus post factam operationem, et uterque non per hebdomades, sed per menses hosce, sensus hujus fallacis diminutionem habere fatebatur. (Lemos. Dissert. inaug. quæ dolorem membri amputati remanentem explicat. Hal. 1798, p. 33.)

g. Nunc temporis etiam ibi versatur juvenis cui ante novem menses brachium sinistrum demtum est. In hoc eadem sensatio sub quinto et sexto mense post operationem decessit, sed mense octavo aliquot dies, ubi vehementior esse cœpit, habuit, ut interdiu tantum ope oculi et nocte ope manus alterius jacturæ hujus se convincere possit. (Ibid. p. 33.) The author of the dissertation from which these cases are extracted, attributes the phenomena to the association between the two extremities, which is not a satisfactory explanation, for this association should first be explained.

h. A toll-keeper in the neighbourhood of Halle, whose right arm had been shattered by a cannon-ball in battle, above the elbow, twenty years ago, and afterwards amputated, has still, (in 1833,) at the time of changes of the weather, distinct rheumatic pains, which seem to him to exist in the whole arm; and though removed so long ago, the lost part is at those times felt as if sensible to draughts of air. This man also completely confirmed our statement, that the sense of the integrity of the limb is never lost.

i. A man whose hand had been amputated, had still, seven years afterwards, namely, at the time of his death, pains which seemed to him to have their seat in the hand. (Klein, in Graefe u. Walther's Journ. f. Chirurg. iii. 408.) Professor Valentin (Repertor. für Anat. und Physiol. 1836, p. 339,) has observed, that indi-

I do not speak of the dreams of individuals who have lost limbs by amputation, nor of the vivid perceptions such persons have of sensations, apparently in the entire limb which is lost, when the stump is pressed upon from the position of the body; for these are necessary consequences of the persistence of the internal sensations of the limb generally throughout life.

IX. *The relative position of the primitive fibres of the nerves at their origins and in the nervous trunks, is not altered by a change of the relative position of their peripheral extremities; and hence we find that, when the relation of the fibres at their peripheral extremity is changed, the sensations of which they are the seat, are referred to the same spots as before.*—This is exemplified in the phenomena observed when the peripheral extremities of nerves have their relative position changed artificially, as in the transposition of portions of skin. When, in the restoration of a nose, a flap of skin is turned down from the forehead and made to unite with the stump of the nose, the new nose thus formed has, as long as the isthmus of skin by which it maintains its original connection remains undivided, the same sensations as if it were still on the forehead; in other words, when the nose is touched the patient feels the impression in the forehead. This is a fact well known to surgeons, and was first observed by Lisfranc. When the communication of the nervous fibres of the new nose with those of the forehead is cut off by division of the isthmus of skin, the sensations are of course no longer referred to the forehead; the sensibility of the nose is at first absent, but is gradually developed.

Another phenomenon, perfectly similar in its nature to the foregoing, and explicable on the same principles, is that, when we cross the fore and middle fingers, and roll a small globular body—for example, a pea—between the opposed surfaces of the fingers, these surfaces being those which in the natural state are turned from each other, we seem to feel two globular bodies. When we touch a small spherical body with two fingers in their natural position, we do not in fact feel a globe, but merely two convex surfaces, which we imagine, or infer, to belong to a globular body. If, now, we cross

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viduals who are the subjects of congenital imperfection, or absence of the extremities, have nevertheless the internal sensations of such limbs in their perfect state. A girl, aged 19 years, in whom the metacarpal bones of the left hand were very short, and all the bones of the phalanges absent,—a row of imperfectly organised wart-like projections representing the fingers,—assured M. Valentin that she had constantly the internal sensation of a palm of the hand and five fingers on the left side as perfect as on the right. When a ligature was placed around the stump, she had the sensation of "formication" in the hand and fingers; and pressure on the ulnar nerve gave rise to the ordinary feeling of the third, fourth, and fifth fingers being asleep, although these fingers did not exist. The examination of three other individuals gave the same results. These observations would seem to show, that in such imperfectly developed limbs the primitive nervous fibres destined for the absent parts are present. And if the cases examined by Prof. Valentin were not examples of spontaneous amputation during the fœtal state, similar to those described by Dr. Montgomery (Dublin Journal, vols. i. and ii.), and Dr. Simpson (Ibid. vol. x.), they would prove that arrest of development does not always depend on deficiency of the nerves of the part.

the fingers, and make the two sides, which were previously external and turned from each other, internal and opposed to each other, the sensations, like the fibres in their connection with the brain, maintain the same relative position as if the fingers had not been crossed.

b. Of the radiation of sensations.

Occasionally it happens that one sensation excites another, or that sensations in disease extend to parts not actually affected. These phenomena are not rare in the state of health. Thus, the tickling sensation in the nose, excited by the influence of a strong light on the eyes, the extensive sensations arising from the excitement of a limited spot by tickling, the general sensations consequent on the irritation of the organs of generation in coitus, are of this nature; as also those excited by the near and startling report of a gun, and the sensations of trickling of water over the surface, and of shuddering, caused by hearing certain sounds, such as the scratching of glass, or by biting sandy substances. The pathological phenomena of this kind are, however, much more numerous: for example, the toothache extends from the situation of the irritating cause over the whole face; pain in one finger extends to the hand, arm, and the other fingers, without our being able in all cases to suppose that the exciting cause of the pain has been actually communicated to all these parts. The radiated sensations are more especially extended when excited by a tumour of a nerve, as in a case related in the Medical Gazette, 1834.[*] After amputation of the thigh, a swelling formed in the ischiadic nerve at its extremity, where it was also firmly united to the cicatrix and bone; after a short time the skin of the entire stump, and sometimes even distant parts, such as the integuments of the abdomen, became affected with severe pain without any inflammatory symptoms; but the stump being amputated at a higher point, the pains did not return. It is only necessary to hold for a certain time to a point of the skin a body of a burning temperature, to convince oneself that sensations can be produced in surrounding nervous fibres, which are not themselves immediately affected by the exciting cause. In the healthy state, such sympathetic sensations would be very inconvenient; hence nature has avoided their occurrence, by making the individual nervous fibres insulated in their action; for if the fibres from ten different points of the skin united to form one fibre before reaching the brain, only one impression from these ten points could be perceived by the sensorium, and it could be referred only to one spot; and if each primitive fibre in its course became united with nine other fibres which were afterwards continued isolated to the brain, the irritation of a single spot of the skin, even in the state of health, would be attended in its propagation to the brain by nine other sensations in other parts. Now, in the healthy state this does not usually occur; and it cannot, because of the isolation of the nervous fibres in their course to the brain. But there are cases which are exceptions to this rule; and how can the secondary sensations in such instances be accounted for?

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[*] Observations on the Neuralgic Affections of stumps after amputation, by Mr. J. F. Crookes. The rationale of the phenomena suggested by Mr. Crookes is very similar to the second explanation mentioned by Prof. Müller.

In what light now are we to regard the action of the sensitive fibres or sensitive nerves thus secondarily affected? Is it reflex action derived from the brain and spinal cord? Does a current pass from the cerebral or spinal extremity of the nerve in a retrograde course to its peripheral extremity? or, if there is no current, but merely oscillation of a nervous principle, does the impression conveyed to the brain by the nerve primarily excited, give rise to a reflex oscillation in another nerve from its cerebral to its peripheral extremity? It is exceedingly probable that there is, at all events, a reflection of the irritation from the spinal marrow or brain upon the nerve of sensation. It must be remarked, however, that if we explain the sympathetic sensations by such reflex action, we must presuppose that currents or oscillations can be propagated in the sensitive nerves in both directions,—from the brain as well as towards it. It is not known whether this be possible, or whether the sensitive nerves can propagate their actions in the centripetal direction only. It is interesting, therefore, to know that we can explain the phenomena, even though the sensitive nerves do not act in the centrifugal direction. We have seen that the same sensation seems to be produced at whatever point of its length a nervous fibre is irritated, whether at its peripheral extremity, at its middle, or at its origin in the brain and spinal cord; and that this sensation is felt in the parts to which the nerve is ultimately distributed: the mere "radiation" of an impression, therefore, from one sensitive nerve in the substance of the brain or cord, so as to affect the origins of other sensitive fibres, will be sufficient to produce sympathetic sensations. We know in fact that, in affections of the spinal cord, the sensations are felt in the peripheral parts of the body; thus inflammation of the spinal cord is attended with violent pain in the limbs. The radiation of sensations may have a similar cause.

c. Of the coincidence of several sensations.

Sensations appear to be clearly defined and distinct in proportion to the number of primitive fibres distributed to the part in which they are excited; the fewer the primitive fibres which an organ receives, the more likely is it that several impressions on different contiguous points will act only on one nervous fibre, and hence be confounded together, producing but one sensation. Prof. E. H. Weber (*Annotat. Anat. et Physiol.* p. 44—81,) has made some interesting observations relative to the degree of distinctness of sensations in different parts of the body, as measured by the power of distinguishing distances. The experiments consisted in touching the skin, while the eyes were closed, with the points of a pair of compasses sheathed with cork, and in ascertaining how close the points of the compasses might be brought to each other and still be felt as two bodies. The experiments were numerous; the following are the results:—The extremity of the third finger and the point of the tongue were found to be the parts of which the sensibility was most acute; a distance of as little as ½ of a line being here distinguished. On the dorsum of the tongue the two points of the compasses to be felt distinctly, that is, to excite two sensations, required to be separated to the extent of two lines. With the extremities of the fingers, and the point of the tongue, the distance could be distinguished most easily in the longitudinal direction; on the dorsum of the tongue, the face, the hairy scalp, the neck, the whole arm, and the foot, the distance between the points of the compasses could be recognised best when they were placed transversely. The following table shows the degree of sensibility of different parts as evidenced by the distances at which the two points of the instrument could be felt as two distinct bodies:—

Point of the tongue	½ a line.
Palmar surface of third finger	1 line.
Red surface of the lips	2 lines.
Palmar surface of second finger	2 "
Dorsal surface of third finger	3 "
Tip of the nose	3 "
The palm over the heads of the metacarpal bones	3 "
Dorsum of the tongue one inch from the tip	4 "
Part of the lips covered by the skin	4 "
Border of the tongue an inch from the tip	4 "
Metacarpal bone of the thumb	4 "
Extremity of the great toe	5 "
Dorsal surface of the second finger	5 "
Palm of the hand	5 "
Skin of the cheek	5 "
External surface of the eyelids	5 "
Mucous membrane of the hard palate	6 "
Skin over the anterior part of the zygoma	7 "
Plantar surface of the metatarsal bone of the great toe	7 "
Dorsal surface of the first finger	7 "
On the dorsum of the hand over the heads of the metacarpal bones	8 "
Mucous membrane of the gums	9 "
Skin over the posterior part of the zygoma	10 "
Lower part of the forehead	10 "
Lower part of the occiput	12 "
Back of the hand	14 "
Neck, under the lower jaw	15 "
Vertex	15 "
Skin over the patella	16 "
———— sacrum	18 "
———— acromion	18 "
The leg near the knee and foot	18 "
Dorsum of the foot near the toes	18 "
The skin over the sternum	20 "
——— over the five upper vertebræ	24 "
——— over the spine near the occiput	24 "
—————— in the lumbar region	24 "
—————— in the middle of the neck	30 "
—————— in the middle of the back	30 "
The middle of the arm	30 "
————— thigh	30 "

The distance between the points of the compasses seemed to be greater when felt by the more sensitive parts than when it was estimated by parts of less distinct sensibility. When the points of the instrument were applied in a line drawn round the thorax, two spots were found, namely, in the middle line before and behind, at which the sensibility was more defined than elsewhere. If the points of the compasses were applied in the same line, but in the direction parallel with the axis of the body, four spots were found especially sensitive; two of these were situated before and behind, in the middle line, and two at the sides. If the points of the instrument were placed either transversely or longitudinally in a line drawn from the chin to the pubes, the sensibility was found to be most distinct on the chin, less on the neck, again more distinct over the sternum, less so at the upper part of the abdomen, again more distinct at the navel, and indistinct in the neighbourhood of the os pubis. In the middle of the back the most defined sensibility was found just below the occiput and over the coccyx. Along the side of the trunk, the most distinct sensibility was found in the axilla and in the groin.[*]

The accuracy with which impressions are perceived does not depend essentially on the presence and number of the papillæ; for the sensibility of the nipple is indistinct, and the most acute sensibility of the tongue is limited to the tip: hence Weber supposes the difference of sensibility to depend on the number, course, and mode of termination of the nervous fibres. I coincide entirely in this opinion, and will merely remark, that the greater or less facility for the radiation of impressions in different parts of the brain and spinal marrow may have some share in the production of these differences.

The greatest power of distinguishing distances by sensation is possessed by the retina. It is interesting, with reference to the laws of sensations, to know that the size of the globules of the retina corresponds to that of the smallest sensible points on it. Weber found that the globules of the retina measured from $\frac{1}{8005}$ to $\frac{1}{8400}$ of an inch in diameter; and the smallest angle of vision at which two points can be distinguished is 40″; from which Smith calculated that the most minute sensitive point of the retina measured $\frac{1}{8000}$ of an inch. Weber remarks, that when two impressions fall upon such a point, they will give rise to but one sensation.[†] Baumgaertner[‡] attributes our indistinct perception of objects, of which the extent is seen at a less angle than 13 seconds, to the physiological radiation of sensations.

A very remarkable instance of the coincidence or "identification" of sensations is afforded by two corresponding nerves of the opposite sides of the body, namely, the optic nerves; no parallel case can be found in the whole body, and it must here depend on some special provision of structure. Impressions on the corresponding sensitive nerves of the right and left sides in no other instance give rise to a single sensation. Similar impressions on the two hands are felt distinctly, not as one sensation; on the contrary, the two being conveyed to the sensorium give rise in it to two distinct sensations. In the eyes or optic nerves, however, we meet with the anomaly that certain fibres of the one nerve with certain fibres of the other have but one and the same sensation, hence the phenomenon of single vision with two eyes.

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[*] Valentin has repeated these experiments on himself and four other persons, with results which agree in the main with those obtained by Weber, but which prove that the same parts of the surface may differ very considerably in the acuteness of their sensibility in different individuals. See Valentin, De Function. Nervor. p. 119.

[†] Weber's edition of Hildebrandt's Anat. i. p. 165.

[‡] Zeitschrift für Physik und verwandte Wissench. ii. Bd. 3 Hft. p. 236.

CHAPTER III.

OF THE REFLEX ACTION BY WHICH IMPRESSIONS ON SENSITIVE NERVES GIVE RISE TO MOTIONS.

The occurrence of motions consequent on sensitive impressions has been known, not merely to the earlier physiologists, but to the cultivators of medicine in all ages. Physiologists have generally followed Willis in ascribing them to nervous communication by means of the ganglionic or sympathetic nerve, which hence acquired the latter epithet. Comparetti (*Occursus Medici.* Venetiis, 1780,) wrote an entire work, for the purpose of explaining the morbid consensual phenomena by communications between nerves. These views were adopted by most physiologists; and even very recently, (see *Tiedeman, Zeitschrift für Physiol.* i. 1825,) new anatomical facts relating to the nerves have received applications agreeing with them.[*]

Some even of the earlier physiologists, however, as Haller, Cullen,[†] Whytt,[‡] Monro,[§] and others, were dissatisfied with this theory of sympathies. Whytt and Cullen believed the phenomena to take place through the intervention of the sensorium, and to be consequent on sensations. It is but very recently, however, that these sympathetic motions have been investigated in an exact and experimental manner. Several important facts, unfavourable to the hypothesis of these phenomena being dependent on the sympathetic nerve, were noticed by Mayo (*Anatom. and Physiol. Commentaries,*) in 1823. It had been usual to attempt to account for the fact of the motions of the iris being determined by the influence of light on the retina by communications supposed to exist between the optic nerve and the sympathetic. But Mr. Mayo's experiments on the nerves of the eye, with reference to the motions of the iris, in which it was shown that these motions are effected by the action of the third nerve, and may be excited by irritation of the optic nerve (as by stretching it) proved that the phenomenon must be produced through the medium of the brain. After dividing the optic nerve within the cranial cavity in a pigeon, he was still able to excite contraction of the pupil by exerting traction on the portion of the optic nerve connected with the brain. The principle of the reflection of the irritation from the sensitive upon the motor nerves through the medium of the central organs of the nervous system, was, however, first shown to be generally applicable in the explanation of all motions consequent on sensations, by the researches of Dr. Marshall Hall* and myself, published in 1833, in which the theory was established by new facts to be the true mode of explaining a great number of known but ill-understood phenomena.†

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[*] The sympathetic movements seem to have been generally attributed by physiologists in Germany, during the last few years, to nervous communications; such, however, has not been the case in this country. The opposite view has been adopted by the modern English authors who have published original works on Physiology. See Dr. Alison's Outlines of Physiology, 1831, and Transact. of the Med. Chir. Society of Edinb. vol. ii.; Dr. Bostock's Elements of Physiology, 1827, vol. iii. p. 224, and Mr. Mayo's Outlines of Physiol. 2d edit. 1829, pages 339 and 344.

[†] Institutes of Medicine, pt. i.

[‡] On Sympathy and Nervous Diseases (in the German edition of Whytt's works, p. 241.)—An Essay on the Vital and other Involuntary Motions. Edinb. 1751, p. 248.

[§] On the Nervou [illegible] ition. 1787.)

A later work (*Memoirs on the Nerv. Syst. Lond.* 1837,) by Dr. Hall contains the continuation of his researches. The facts observed by Dr. Hall and myself are very similar, but we differ much in our mode of explaining them. I have brought forward arguments in favour of the old opinion of the reflection of impressions from sensitive nerves upon motor nerves through the intervention of the central organs. Dr. Marshall Hall, on the contrary, in his last work, introduces an entirely new principle into the explanation, which is thereby rendered quite distinct from that which I adopt. Volkmann has added several important facts confirmatory of the doctrine of reflex action. The following is my view of the subject, as given in the former edition of this work, together with a sketch of Dr. Hall's investigations, and a comparison of the different views offered to explain the phenomena:—

When impressions, made by the action of external stimuli on sensitive nerves, give rise to motions in other parts, these are never the result of the

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* The paper of Dr. Hall, which is here referred to, appeared in the second part of the Philos. Transactions for 1833. I first stated my views in the first edition of the first part of this work, which appeared in the spring of that year, in the chapter on the Respiratory Movements, and more fully in the second part of the work in the following year, 1834, after Dr. Hall's paper had appeared. A paper by Dr. Hall had, however, been read at the Zoological Society on this subject in 1832; he has, therefore, the priority. Dr. Hall published an account of my views, and a comparison of them with his own, in the Lond. and Edinb. Mag. vol. x. No. 58.

† Here Professor Müller is certainly in error. Earlier physiologists have taken an extended view of the sympathetic or reflected motions; they have recognised the principle of their dependence on an impression conveyed to the brain and spinal cord, have distinguished them from the motions dependent on consciousness and volition, and have even indicated the parts of the central organs of the nervous system which are capable of reflecting impressions communicated to them by sensitive nerves, so as to excite motions. See especially Dr. Henry Ridley (Anatomy of the Brain, cap. xviii. p. 162, et seq.), Dr. Whytt (On the Vital and other Involuntary Motions of Animals. Edinb. 1751. Works, p. 153, 163, 506, and 511). Cullen (Works, vol. i. p. 109, et seq.), and Prochaska (Annotat. Academicæ, 1784. Opera Minora, 1800. Lehrsätze aus der Physiologie. Wien. 1797.)—*Translator.*

direct reaction of the sensitive and motor fibres of the nerves on each other; the irritation is conveyed by the sensitive fibres to the brain and spinal cord, and is by them communicated to the motor fibres.—This law, which is of extreme importance in physiology and pathology, from its explaining a great number of phenomena, requires to be strictly proved, and this can be done by experiment.

I will, in the first place, demonstrate that, after the union of the two roots of a nerve, the sensitive and motor fibres themselves do not unite, but are continued quite distinct from each other to the parts which they respectively supply; and hence, that in the cases also where nervous sympathy is not in play, the sensitive and motor fibres in the nerve itself have no reciprocal action on each other. This may be easily proved in the following manner:—Having divided a mixed (motor and sensitive) nerve, irritate the portion of it which is connected with the brain or spinal cord; violent pain will be produced, which the animal may express by movements of flight, by cries, &c.; but the motor fibres of the branches coming off from the irritated portion of the nerve are not excited to action, no contractions of the muscles to which they are distributed take place.

1. In many animals, by the mere division and contusion of the spinal cord. Thus, every touch excites general spasms in the tortoise after its decapitation; the same phenomenon is produced in very young birds, if they are touched the very moment after they are decapitated, and, as we have shown, in all parts of the trunk of the land salamander after it had been cut into many segments.

2. The same degree of irritation of the spinal cord exists in frogs during the first stage of poisoning by narcotics; and also in Mammalia, in which, after poisoning by nux vomica, general spasms are immediately produced, when they are laid hold of at any part or in any manner. This state of excitable exhaustion (reizbare Schwäche) almost always precedes the stage of paralytic exhaustion.

3. Other causes, also, which produce exhaustion of the brain and spinal marrow, by excessively exciting them, give rise to the same phenomenon. In persons in whom the nervous system is in that state of exhaustion which is accompanied with great excitability, every sudden impression on the nerves, whether by sound, touch, or mechanical shock, causes the whole frame to start. Such a state of the spinal cord is produced by excitement of the generative organs, and through them of the spinal cord, and by other causes. We may here remark, that any excitement of the nervous system may induce three states in succession: First, the state of excitement with the powers unimpaired; secondly, in proportion as the excitation is repeated, a state of exhaustion with excitability; and thirdly, atonic exhaustion.

4. Severe local irritation of the sensitive nerve may, by the intensity of the impression conveyed to the brain and spinal marrow, give rise to twitchings of the muscles and tremours, as we observe to be produced by severe local burns, extraction of a tooth, &c.

5. Local irritation of the nerves, from inflammation or ganglionic enlargements, also frequently gives rise to general spasms, even to epilepsy.

6. The irritation of the spinal cord, arising from local excitement communicated by sensitive fibres, may be so intense that the spasms are constant, and continue without any new stimulus, such as the contact of a substance with the surface. Such is tetanus traumaticus, a violent irritation of the spinal cord, arising from severe injuries of the nerves. Every intense irritation of the spinal marrow generally is tetanus, whether it be caused by narcotic poisons acting directly upon it, or by local irritations conveyed to it through the nerves. The production of tetanus is intelligible, if the above facts established by experiment are taken into consideration.

7. Great irritation of the sympathetic nerves in the intestinal canal likewise, being propagated to the central organs of the nervous system, gives rise to secondary general cramps: it is thus that we must explain the cramps which attend sporadic cholera, and the intestinal affections of children.

The facts thus far considered, merely lead us to admit, as a law, that, whenever general spasms are excited by local impressions, the phenomenon depends on no other communication between the sensitive and motor fibres than what exists in the spinal cord. In very many cases, however, local irritation of the nerves gives rise, not to general, but to local muscular spasms; in which case, again, the spinal cord is to be regarded as the bond of communication between the sensitive and motor fibres. The cases of this kind are the following:—

1. The most simple is that in which the local irritation of the sensitive fibres being propagated to the spinal cord or brain, excites merely local spasms,—spasms, namely, of those muscles, the motor fibres of which arise from the same part of the spinal cord as the sensitive fibres that are irritated. Of such a case we have instances in the spasms and tremours of limbs on which a severe burn is inflicted, &c. Certain parts of the frame which are exceedingly excitable,—for example, the iris,—are very readily made to contract, even when only feeble stimuli affect other sensitive nerves. It has been long known that the action of light on the iris itself does not excite its contraction, that the light effects the iris through the medium of the optic nerve and brain; for this was proved by the experiments of Lambert, Fontana, and Caldani. Rays of light, passed through a small cone of paper, or through a hole in a sheet of paper, and directed so as to fall through the pupil upon the retina, excite immediate contraction of the iris, but have no such influence when made to fall upon the iris itself. The iris of an amaurotic eye, again, is fixed as long as the sound eye is closed, but contracts when the sound retina is exposed to the stimulus of light. The exceptions to this rule, in which the iris of amaurotic eyes has possessed mobility, (see *Tiedemann's Zeitschrift*, i. p. 252,) may have been cases of imperfect amaurosis; or, if only one eye was amaurotic, the motion of the iris in the diseased eye might have arisen from the other eye being open. Among the most simple cases of reflected excitation, may be instanced also the winking of the eyelids under long-continued influence of light, or in consequence of a loud noise, or a threatening impression on vision.

In the case also of the contractions of all the perineal muscles in expelling the semen, which are excited by irritation of the sensitive nerves of the penis, the spinal cord is the medium of communication between the sensorial impressions and the movements.

2. The second case is that, where the excitement of the sensitive nerves is entirely local, but the reflected influence from the brain more extended. Of this we have an instance in the phenomena accompanying coughing; in which not merely the vagi, but, to produce the contractions of the thoracic and abdominal muscles, the spinal nerves also are called into action. A number of spasmodic movements of the organs of respiration, as sneezing, hiccough, vomiting, &c. are produced in the same manner; they all arise from irritation of the pulmonic and intestinal tracts of mucous membrane, that is to say, from irritation of the sensitive nerves of these parts, which is propagated to the brain, and there excites to action the source of motor power for the respiratory movements which is the medulla oblongata. It appears almost certain that the ordinary respiratory movements also are the result of a reflex nervous action, (see the account of the respiratory movements in the 4th Book.) We have already noticed in the section on respiration the remarkable circumstance, that the whole system of respiratory nerves can be excited to action by irritation of any part of the mucous membranes, from the mouth to the anus, from the nostrils to the lungs. The mode of production of sneezing we have already explained.

Any considerable irritation in the intestines or urinary organs has a tendency to cause contraction of the diaphragm and abdominal muscles, by which a diminution of the cavity of the abdomen is produced and its contents expelled by the mouth when in the stomach, or otherwise by the anus, by the urinary organs, or by the generative organs, as in parturition. The expulsion of the fœtus in some cases after the death of the mother, and the fact that the finger introduced into the pharynx of a decapitated animal is tightly seized, show us the importance and intimate connection with life of this property which the spinal cord enjoys of issuing its motor influence when its sensitive nerves are affected by a local stimulus. If the sympathetic plays any part in the production of these phenomena, for instance, in vomiting, it can do so only by transmitting to the central organs, like all other sensitive nerves, the impression made upon its peripheral extremities. And it certainly may have this action, for by irritating the splanchnic nerve with a needle, I have been able to produce contractions of the abdominal muscles in rabbits.

3. In the second kind of cases, the reflex action affects a large group of nerves—the respiratory nerves, and it is excited most frequently by irritation of a mucous membrane. When this irritation, however, is more intense, the irritation of the spinal cord becomes extensive, and is reflected upon almost all the nerves of the trunk. Thus, in severe cases of sporadic cholera (the Asiatic cholera I do not refer to, on account of the obscurity of its nature), cramps sometimes affect even the trunk.

4. In the reflected motions produced by violent impressions on the sensitive nerves of the skin, and not of the mucous membranes, the respiratory movements are not sympathetically excited,* but rather spasmodic contractions of the muscles supplied by the whole system of nerves of the trunk, without any spasmodic movements of respiration. Of the extreme degree of such an affection we have instances in the epileptic convulsions from local affections of the nerves, and in traumatic tetanus from injury of a nerve.

Dr. Marshall Hall distinguishes four kinds of muscular contraction:—

1. The voluntary, which appears to be dependent on the brain.

2. The respiratory, for which the nervous influence is apparently derived from the medulla oblongata. With regard to these movements Dr. Hall has since altered his opinion. He now classes them with the excited movements dependent on reflex nervous action.

3. The involuntary, dependent merely on the nerves and muscles, and requiring the direct application of the stimulus to the muscles provided with nerves, or to the nerves of the muscles.

And, 4. The reflected muscular motion, which subsists in part after the voluntary and respiratory motions have ceased, and which is attached to the spinal cord, ceasing itself when this is removed, and leaving the mere muscular irritability undiminished.

All the phenomena agree in the circumstance of the spinal cord being the medium of communication between the centripetal nervous action produced by the exciting stimulus, and the subsequent motor action of the nerves; but the different "paths" of communication in the spinal cord may be more distinctly defined. The most common form of reflected motion is that where violent impression on sensitive nerves excites muscular contractions in the same limb: this is observed when the skin is burnt; and, in the first stage of narcotisation of an animal, a stimulus applied to the skin excites contractions most readily in the irritated part: thus, also, the stimulus of the food in the fauces excites the act of deglutition; dust on the conjunctiva, closure of the eyelids; and the irritation of the urine and fæces, the contraction of the sphincters. Hence we see that irritation propagated to the spinal cord most readily affects those motor nerves which arise nearest to the roots of the exciting sensitive nerves: in other words, that it is most prone to pass from the posterior roots, or the individual fibres of these roots, to the anterior root of the same nerve, like electricity, leaping by the most direct course from one pole to the other. To express it more correctly, and in the language of physiology, we may say that when the motor influence of the spinal cord is strongly excited by a sensitive nerve, that part only is at first affected which is nearest to the root of that nerve; and that the irritation of the cord, and of the motor nerves arising from it, diminishes in proportion with the distance from that point. In the same way, in the brain the irritation is communicated from certain sensitive to certain motor nerves. Thus, as we have shown, the optic and acoustic nerves, and the sensitive branches of the fifth nerve, are prone to excite reflex actions of the ciliary branches of the third pair and of the facial nerve. In their original formation, indeed, some provision must have been made for the reaction of the roots of these nerves on each other. Mr. Mayo* seems to maintain that proximity of origin is a general condition when sentient and motor nerves are thus associated in their functions.

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* A sudden application of cold to the surface, however, is well known to excite a spasmodic movement of inspiration.

The sensitive and motor nerves which thus react on each other through the medium of the brain and spinal cord, seem to stand in such a mutual relation, that a change in the condition of one produces a change in the other; just as one scale of a balance rising causes the other to descend, or as the sinking of a fluid in one branch of a bent tube makes it rise in the other.

The form of reflex action next in frequency to that just described, is the production of spasmodic contractions of the respiratory muscles from irritation of the mucous membranes. Hence there must pre-exist in the medulla oblongata and spinal cord some means of ready communication between the sensitive nerves of the mucous membranes (the fifth nerve in the nostrils; the vagus nerve in the trachea, lungs, pharynx, œsophagus, and stomach; the sympathetic nerve in the intestines and uterus; and branches of the sacral plexus and the sympathetic nerve in the urinary bladder and rectum,) on the one hand, and the motor nerves of the respiratory muscles (the facial, accessory, and certain spinal nerves,) on the other; while the spinal nerves which go to the extremities are excluded from this harmony of action.

There are, however, certain states of irritation of the spinal cord and brain, produced by the action of narcotic poisons, or other causes, in which every impression on a sensitive nerve is capable of exciting the spinal marrow to a discharge of motor influence by all the motor nerves, even by those which are least prone to be affected by reflex action,—namely, the motor nerves of the extremities. Volkmann has, indeed, shown that even dividing the spinal cord longitudinally in frogs previously decapitated does not prevent the extension of the reflex motions to the muscles of both sides of the body, so long as the two halves of the spinal cord remain connected at any point. This experiment has been repeated with the same result by Valentin. (*De Function. Nervor. Cereb. et Sympath.* Bern. 1839, p. 99.)

We have, lastly, to inquire how far true sensation is engaged in the production of the reflex motions. Volkmann inclines to the opinion of Whytt, that the motions consequent on impressions are the result of an appropriate voluntary reaction of the sensorium excited by sensation.†

That this is in many instances the case, appears to me to be indubitable, particularly with those reflex phenomena which occur in an unimpaired state of the brain and spinal cord. Thus I regard, for example, the closure of the eyes under the stimulus of a strong light, and the action of the respiratory muscles induced by irritation of the mucous membranes of the respiratory organs, intestinal canal, or urinary system. But when we remember that, if we divide the trunk of a Salamandra maculata into several portions, each part, if it contain a fragment of the spinal cord, will still evidence the reflex motions, we can scarcely maintain the applicability of this view to all cases. The reflex phenomena are observed also to occur in parts withdrawn from the influence of the will, such as the intestinal canal and heart. The general spasms, lastly, which are excited by stimulus of a sensitive nerve in animals in a state of narcotisation do not in the slightest degree resemble the phenomena of spontaneous reaction. The view which I take of the matter is the following: Irritation of sensitive fibres of a spinal nerve excites primarily a centripetal action of the nervous principle, conveying the impression to the spinal cord; if this centripetal action can then be continued to the sensorium commune, a true sensation is the result; but if, on account of division of the spinal cord, it cannot be communicated to the sensorium, it still exerts its whole influence upon the spinal cord. In both cases, a reflex motor action may be the result. In the former case, the centripetal action excites, at the same time, sensation; in the latter case it does not, but is still adequate to the production of reflex motion, or centrifugal reflection.*

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* See his observations on the origins of the cerebral nerves, at page 343 of his Outlines of Physiology. Second Edition, 1829.

† Whytt did not, however, believe volition to be engaged in the production of all, at least, of these motions. See pages 153, 162, and 511, of his works.

Dr. Hall's theory differs from that of Whytt, as well as from my own, and is peculiar. In the first place, he limits the phenomena of reflex action to the spinal nerves, and denies to the cerebral nerves of special sense the power of exciting them. He supposes the reflex motor actions to be in no case excited by sensation, nor even by means of the sensitive nervous fibres. He maintains the existence of special nerves, or nervous fibres, endowed with the "excito-motory" function; and the reflex action he supposes to be conveyed, not by the nerves of spontaneous motion, but by special fibres, which he calls "reflecto-motory."

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* Irrefragable proof that the reflex movements are independent of sensation is afforded by certain phenomena of disease. In cases of paraplegia dependent on lesion of the dorsal or cervical portion of the spinal cord, its lumbar portion remaining healthy, slight irritation of the surface of the lower extremities, as by tickling the sole of the foot, the passage of a catheter, or the evacuation of the fæces, will produce convulsive movements of the feet and legs, even though they be perfectly devoid of voluntary power and sensation. The first cases of this kind adduced in illustration of the theory of reflex movements were observed by Mr. Barlow, Dr. Budd, and Mr. Barron (see Dr. Hall's Memoirs, p. 63; and Mr. Grainger's Observations on the Spinal Cord, p. 93). They are now familiar to pathologists. (See an interesting paper by Dr. W. Budd, in the 22nd vol. of the Med.-Chir. Transactions.) In cases of hemiplegia the same phenomena occur; an instance of which, observed by the translator, was related in the last edition of this work, p. 721. Dr. Reid remarks that the sensations which attend some of the reflex motions have been added for an ulterior object—that it is necessary both for our comfort and well-being, that these movements (such as those by which the contents of the bladder and rectum are expelled) should be influenced by volition, and that this, of course, could only be accomplished by associating sensation with the excitation of the impression.—*Translator.*

(*a*) The chief facts connected with the present doctrine of reflex movements may be summed up in a few sentences. It was well known that independently of volition, a number of muscular movements ensued on the excitement of a sensitive surface; as in the familiar example of a person who is asleep, turning himself away from the light of a window, or throwing up his hands to his face to remove anything tickling his nose or eyelids, but without in either case awaking. Observations on anencephalous infants and experiments on animals by ablation of the cerebrum, leaving only the nerves at the basis of the brain and the medulla oblongata untouched, also, proved that a circle could be established without the intervention of the sensorium at all, as in the movements of the eyelid, consequent upon the exposure of the eye to light, or efforts at mastication and deglutition, when food is introduced into the mouth. To the same purport are convulsive movements, which ensue in decapitated cold-blooded animals, when any part of their skin is pinched or even touched. The circle in the first of this class of cases was, I should say, by the sensitive nerve to the medulla oblongata, and thence to the motor nerves of the eye, mouth and fauces. In the second the circle was obviously the sensitive nerves, the medulla spinalis, and the motor nerves to the locomotive muscles. Examples of a nature analogous to the last mentioned class, are met with in the human subject in hemiplegia, an example of which I have myself witnessed in a little patient, in whom the paralysis was the consequence of injury of the dorsal vertebræ, who could be made often to move his legs by moderate and equable friction of the skin of these limbs, exercised with the hand of another person.

Physiologists were acquainted with these and numerous other phenomena of a kindred nature; but it is only within a few years past that they have been embodied into a system chiefly by Dr. Marshall Hall, who argues, that the movements just described are not only executed independently of volition, but also of sensation, and that both at the basis of the brain and the spinal marrow, the nerve which is the conductor of the impression or the exciter serves as a stimulus to the nerve which is distributed to the muscle or the motor, and that the two constitute a circle which, when in activity, gives rise to reflex movements independently of the fibres of the central mass or cord—cerebrum or spinal marrow—and the common sensitive and motor nerves which are united by its intervention. Of course the most that could be said of this view, however it might be illustrated by physiological or pathological phenomena, or sustained by plausible analogies, was, that it is a mere hypothesis, the phraseology of which represented nothing new, but which if adopted might save some paraphrases. Much of the discussion turned for a while, and indeed, must still turn on the idea attached to the word

(*a*) The three following paragraphs are introduced by the Editor.

sensation. They who believe that sensation must be followed by perception or consciousness, will regard all movements consequent on impressions on nerves or nervous conductors of which we are not conscious as automatic, and to be explained by such an hypothesis as that of Dr. Hall. But if we admit that the same nerve which to a certain amount of stimulus is directly sensitive, that is, forces the brain to be cognisant of its excitement, may with less stimulation be a conductor of impression to a common centre—brain or spinal marrow—without consciousness, but just exciting the latter enough, for it to transmit the impression into the motor nerves, we need not any additional hypothesis.

I will give a familiar example, derived from my own person, in illustration, instead of the mere supposition which I have just introduced. Frequently, when reclining on an easy chair, I extend my legs on another, which is a little too high, and withal, hard and uneven, for perfect ease. Now it sometimes happens that, before falling into a state approaching to sleep or a doze, my lower limbs undergo a quick and involuntary contraction, or jerk without any prior positive sensation in them. It is not the start which sometimes precedes sleep when we are in bed and imagine that we are about to fall from some height; but it is the consequence of direct excitement of the sensitive nerves of my legs, caused by the uneven borders of the chair transmitted to the spinal marrow, which irradiates its motility on the nerves distributed to the muscles of these parts. That the movements of the legs proceed from impressions on them, is plain by the fact that when the latter rest on a pillow, no jerks or contractions are ever produced. The question now presents itself—is the circle in this case, different from the circle acted on when I voluntarily withdraw my legs in consequence of a pin pricking them, or the skin being tickled with a feather, or any other universally admitted *sensation?* Is the first to be called excito-motory action or reflex movement, in which sensation does not participate, and the second a movement following sensation? Or, although we may choose to use different phraseology, are we justifiable in assuming two different nervous circles to explain these phenomena? Are there two sets of *afferent* nerves, one for sensation, or sensitive, and one for impression, without sensation, or excito-motory? And are there two sets of *efferent* or motor nerves, one for voluntary movements, and the other for reflex movements—the former in relation to and connection with the sensitive nerves, the latter in relation to and connection with the reflecto-motory? Dr. Hall would reply in the affirmative to these questions.

The posterior roots of the spinal nerves, and nerves of the medulla oblongata, according to Dr. Hall, contain sensitive and excito-motory fibres; the anterior roots, spontano-motory and reflecto-motory fibres; the vagus, too, he regards, not as a nerve formed chiefly of sensitive fibres, but as an excito-motory nerve; for, in an experiment performed by himself and Mr. Broughton, its division gave rise to no pain, but affected the movements of respiration. Dr. Hall has recently developed these views more fully. (*Memoirs on the Nervous System.* London, 1837.) Volkmann disputes their validity, and, among other arguments, states as does Dr. Reid (*Edinb. Med. and Surg. Journ.* vol. 49 and 51,) also, that Dr. Hall is incorrect in asserting the vagus to be insusceptible of painful sensations.

The theory of Dr. Hall, that the nervous fibres engaged in the production of the reflex or excited movements, are distinct from those which reach the centres of sensibility and volition in the brain, was not, says Dr. Baly, established by the facts which he himself adduced in its support. It has, however, acquired a great degree of probability from the arguments more recently brought to bear on the subject by Mr. Grainger and Dr. Carpenter. Mr. Grainger* seeks first to prove that grey matter is the source of all power in the nervous system, and that the white fibres are merely conductors; instancing, that the nerves are rendered incapable of performing their functions by separation from the central organs; that the power of those central organs is always proportionate to the quantity of grey matter which they contain; that the abundance of grey matter in the brain, for example, bears a direct relation to the development of the cerebral faculties, and its abundance in the spinal cord, to the motor powers of the animal; and, lastly, that even in particular parts of the cord, where large nerves enter and issue, a corresponding increased deposit of grey substance is found. He next directs attention to the roots of the spinal nerves, and shows that while a portion of the fibres of each root is derived from the white fibrous substance of the cord, another portion passes inwards, and is lost in the grey matter, as had been stated by Bellingeri and Weber. The latter fibres Mr. Grainger regards as the true excito-motory and reflecto-motory fibres, the former he supposes to be the conductors of sensation and volition ascending to or descending from the brain. These views he extends to the cerebral nerves, and states, that they also may be traced to have origins both from deposits of grey matter where the impressions conveyed by incident fibres are communicated to reflex motor fibres, and also from the white substance which passes up to the hemispheres of the cerebrum and cerebellum. Lastly, Mr. Grainger points out the accordance of Dr. Hall's theory with the structure of the nervous system in the lower animals; but his views respecting the Invertebrata, though essentially the same as those since developed by Dr. Carpenter, were expressed in so cursory a manner that they attracted little notice; and seemed not to add great weight to his other arguments. The following are some of the most important conclusions deduced by Dr. Carpenter† from a review of the structure of the nervous system of invertebrate animals:—the actions performed by the lowest animals have almost entirely the character of reflex movements, the manifestations of true sensibility and volition which they present being very few. The earliest form of nervous system met with in these animals consists of ganglia with nerves which convey to them the impressions made by external agents, and others which conduct the reflex motor influence; the principal sets of organs with which such ganglia are connected being those which minister to the functions of the ingestion of food, respiration, and locomotion. In proportion, however, as the development of organs of sense and the character of the movements prove the participation of the faculties of true sensation and volition in the acts of the animal, particularly in those by which food is acquired, certain ganglia, connected with the organs of sense, and, like them, always seated near the mouth, acquire a larger size, and an evident predominance over the rest. Yet, even where this is the case, as in the higher Mollusca and Articulata, the organs by which the food is introduced into the stomach, the organs of respiration and those of locomotion, still remain under the immediate influence of special ganglionic reflecting centres, while distinct fibres descend from the cephalic ganglia and unite with nerves issuing from these local nervous centres, for the purpose of conveying to the different organs the influence of the will, and of receiving the impressions destined to produce sensations.

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* Observations on the Spinal Cord. London, 1837. Chap. II. and III. et passim.

† Inaugural Dissertation on the Nervous System of the Invertebrata. Edin. 1837.

It has been long recognised that the spinal cord of the higher animals might be regarded as containing a succession of independent reflecting centres; but the reflecting action of the centres or segments of the cord seemed explicable without admitting Dr. Hall's theory of the existence of special incident and reflex fibres. Even when Mr. Grainger pointed out the accordance of that theory with the mode of origin of the spinal nerves, it still appeared possible that the fibres which entered the grey substance of the cord might, through the medium of it, act on each other, and nevertheless be afterwards continued upwards to the brain. Now, however, since the existence of two distinct classes of fibres, those for sensation and volition, and the fibres which are engaged in the production of the reflex movements, seems to be demonstrated in the invertebrate classes, and Dr. Hall's theory, therefore, to be correct with regard to them, there appears to be no reason for the adoption of a different explanation of the same phenomena in the Vertebrata, where the function and intimate structure of the nervous system are in all other essential points the same. No positive argument of any weight was ever urged against Dr. Hall's theory. An additional one in its favour may, perhaps, be found in the circumstance of the size of the encephalon in many fishes being apparently inadequate for the reception of all the fibres of the various nerves of the body, notwithstanding that their diameter is confessedly diminished when they enter the central organs.

Volkmann points out a fact which we have ourselves often observed, namely, the great difference between the nerves themselves, and their peripheral terminations, in the power of exciting reflex motions. No part equals the skin in the property of exciting reflex motions; the slightest touch applied to the surface, in animals in a state of narcotization, is frequently sufficient to give rise to strong spasms, while the reflex actions excited by irritation of the nerves themselves are much slighter.*

CHAPTER IV.

OF THE DIFFERENT ACTION OF THE SENSITIVE AND MOTOR NERVES.

Experience has taught us that, when a nerve is irritated at any point, the reaction of the nervous fibres is manifested through their whole length; in a motor nerve exciting the contraction of muscles with which they are connected, and in a sensitive nerve, whose connection with the central organs of the nervous system is not interrupted, sensation. To explain this, it might be supposed that the effect of the irritation is propagated equally in both directions,—towards the peripheral extremity of the nerves, and towards its cerebral extremity: but it is equally conceivable that the irritation may be propagated in one direction only, namely,—in the fibres which excite motion, towards the muscles; in those which excite sensation, towards the brain. The latter was the view usually adopted before it was known that there were distinct motor and sensitive fibres. The question as to which supposition is correct, still presents itself; and its solution is of extreme importance in reference to the physiology of the nerves. *Is the nervous principle or force of the motor fibres different in its quality from that of the sensitive fibres? or are what are here called the motor and sensitive principles, actions of the same nervous principle, differing only in direction,—being centrifugal in the motor, and centripetal in the sensitive fibres?*

The fact that the nerves of the different senses, when affected by the same stimulus, become each the seat of its peculiar sensation,—the mechanical or galvanic stimulus exciting in the optic nerve the sensation of light, in the auditory nerve that of sound, and in the nerves of touch that of pain,—cannot be adduced in favour of either hypothesis; for it is explicable not only on the supposition that the forces of the different nerves are different, but also on that of the centripetal actions of the same forces being transmitted to different and differently endowed parts of the brain. It is remarkable, however, that many stimuli act only on particular nerves. Thus, light affects only the optic nerves; and, as a warming agent, the nerves of touch, but no other nerves; and the olfactory nerve would appear to become the seat of smell, under the influence of no other stimuli than odoriferous substances and electricity.

However this may be, it is certainly not satisfactorily proved that the sensitive fibres are capable only of centripetal action, and the motor fibres only of centrifugal. There is one circumstance, in particular, which excites still greater attention in reference to this subject. It is the fact noticed at page 512, that for the preservation of the excitability of the motor nerves their communication with the central organs of the nervous system is necessary: this is in appearance in favour of all nerves, including the sensitive nerves, being equally dependent on the brain and spinal cord; in which case, however, there would be centrifugal emanations from the latter organs through the sensitive nerves. Future experiments founded on well conceived ideas or new discoveries must decide the question: and we can, at present, only congratulate ourselves that the investigation of this important problem, on the decision of which so many others depend, has by the observations above detailed been at least introduced into the province of experimental physiology.

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* This fact was noticed by Dr. Whytt, and was adduced by him as an argument for the dependence of the sympathetic actions on peculiar sensations.

If this first question cannot be decided, still less can it be proved that the centripetal and centrifugal conductors form a continuous circle in which a constant current of the nervous fluid is kept up from the central organs through the motor nerves, and from the peripheral extremities of these through the sensitive nerves back to the central organs. It might be imagined that life is constantly attended with a circulation of the nervous fluid, which would be capable of being reduced only to such a low degree of activity as would give rise, on the one hand, to the imperceptible constant play of the muscular fibres in the state of apparent rest,—the antagonistic action of the different muscles; and, on the other, to the indistinct feeling by which a healthy person is made conscious of the existence of the different parts of his body. This hypothesis of the circulation of the nervous fluid, or of the propagation of its vibrations in a circle through the two kinds of nervous conductors, is, however, for several reasons very improbable; for, since many nerves are sensitive only, these must either not be the seat of a circulation, or we must suppose again that with their sensitive fibres they contain an equal number of fibres of centrifugal action, which do not give rise to motions, only because they do not terminate in muscles. If, indeed, we regard those motor and sensitive nerves which communicate by anastomoses of their fasciculi, as in the instance of the facial and infra-orbital nerves, still less can we find in them the means for a circulation of the nervous fluid; for, in the first place, these anastomoses are not real communications of the primitive fibres; and secondly, an irritation excited in the facial nerve is proved by the experiments of Gaedechens, not to be communicated through these anastomoses to the trunk of the infra-orbital nerve so as to excite pain. All these considerations teach us that the existence of a regular circulation of the nervous fluid from the brain and spinal cord through the nerves back to the central organs, not only cannot be demonstrated, but in the present state of our knowledge appears very improbable.

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CHAPTER V.

OF THE LAWS OF ACTION OF THE SYMPATHETIC NERVE, AND THE PROPAGATION OF IMPRESSIONS IN IT.

Our knowledge of the mechanical laws according to which the sympathetic nerve acts, is still extremely incomplete: in this department of physiology little more has been done than to propose certain hypotheses, none of which can be either proved or decisively refuted. The only way in which we can arrive at accurate knowledge on the subject, is to compare with the phenomena presented by the sympathetic nerve, the facts which are ascertained with regard to the action of the cerebro-spinal nerves, and to investigate by new observations how far the mode of action of the sympathetic differs from that of other nerves. We have to inquire, therefore, whether the fibres of the sympathetic are, like those of the cerebro-spinal nerves, insulated in their action, or whether they can impart their influence to each other; whether the radiation of the motor influence, and the coincidence or confusion of different impressions, is not the normal mode of action in this nerve; whether the ganglia are multiplicators of the nervous influence, and as it were small independent nervous centres or points of radiation; whether there is not in these ganglia a reflection of the nervous influence in certain directions; whether the ganglia are the cause of the indistinct and vague character of the sensations in the sympathetic; whether they are organs on which the radiation or confusion of sensations depend, or imperfect conductors which impede the transmission of impressions to the brain and spinal cord, and of the influence of the will to the parts supplied by their branches; or whether they are not rather the central parts from which the organic influence of the sympathetic nerve emanates for the regulation of the organic chemical processes; lastly, whether impressions are propagated from an irritated point of this nerve in the centripetal or the centrifugal direction, or in all directions. It is to be lamented that none of these questions admit at present of a decisive answer. Of the few facts that we know with certainty respecting the action of the sympathetic nerve, part only have relation to them; and of the hypotheses respecting the uses of the ganglia especially, not one can be definitely proved or refuted.

The sources whence the motor and sensitive fibres of the sympathetic nerve are derived have recently been investigated by M. Valentin. From experiments performed on nearly three hundred animals immediately after death, and consisting in irritating different nerves either by mere division, by compression, or by chemical agents, he has obtained the following results respecting the roots in which the motor fibres of different internal organs issue from the spinal cord and the nerves in which they pursue their further course.

Organs.	Roots from which their motor fibres are derived.	Nerves in which they are distributed.
1. Heart.	The roots of the nervus accessorius and of the first three (or four) cervical nerves.	The nervus accessorius before it has joined the vagus; the cervical portion of the vagus, particularly at its superior and middle parts. The inferior cervical part of the sympathetic, and the inferior cervical ganglion. The first thoracic ganglion of the sympathetic, the cardiac nerves, and the cardiac plexus.
2. The pharynx and superior part of the œsophagus.	The roots of the nervus accessorius (of the hypoglossal nerve?) and of the two or three superior cervical nerves.	The pharyngeal branches of the vagus. The pharyngeal plexus. The communicating branches from the hypoglossal nerve to the pharyngeal branch of the vagus and to the pharyngeal plexus; (the communicating branch of the first cervical nerve to the pharyngeal plexus?) The branches from the superior cervical ganglion to the pharyngeal plexus.
3. Inferior cervical part of the œsophagus.	The roots of the nervus accessorius (the hypoglossal?) and of the middle cervical nerves.	The cervical part of the sympathetic nerve (in the rabbit) or it conjoined with the vagus (in the horse and dog). The contiguous branches of the cervical nerves.
4. The thoracic part of the œsophagus.	The roots of the fourth and fifth (third or sixth) cervical nerves.	The inferior cervical ganglion of the sympathetic. The first, second, third, and lower thoracic ganglion. The thoracic plexus. (The cervical portion of the vagus?)
5. The stomach.	The roots of the fourth, fifth, sixth, and seventh cervical nerves (and in the sheep of those of the two superior thoracic nerves).	The cervical portion of the vagus. The thoracic and abdominal parts of that nerve. (The great splanchnic nerve?)
6. The intestines.	The roots of the third cerebral nerve, of the nervus accessorius (in the cat), and of all the dorsal and lumbar spinal nerves.	The thoracic and abdominal portions of the sympathetic. The greater and less splanchnic nerves. The cœliac and the superior and inferior mesenteric plexuses.
7. The ureter.	The lumbar spinal nerves.	The middle and inferior lumbar portions of the sympathetic.
8. The urinary bladder.	The middle and inferior lumbar nerves.	The most inferior abdominal and the superior sacral portions of the sympathetic.
9. The Vas deferens.	————	The inferior pair of lumbar ganglia, and the first sacral ganglion of the sympathetic.
10. The uterus and Fallopian tubes.	The roots of the middle and lower lumbar nerves.	The inferior abdominal portion, and the superior sacral portion of the sympathetic.

With respect to the sources of the sensitive fibres of the sympathetic, Valentin was not able to ascertain any very new facts. He satisfied himself, however, by experiment, that the sensitive, like the motor fibres, descend some distance in the trunk of the sympathetic before being distributed to the different organs. He found that when the communicating branch connecting one of the lateral ganglia with the corresponding spinal nerve was divided, the ganglion and the peripheral branches which issued from it were still sensible (pain could be produced by irritating them), provided the cord connecting the ganglion with the one above was perfect. (*Valentin. De Functionibus Nervorum.* Bern. 1839, p. 61–71.)

a. Of the actions of the sympathetic nerve in involuntary motions.

I. *All the parts subject to the influence of the sympathetic nerve are incapable of voluntary motion.*—The heart, the intestinal canal, the efferent ducts of glands, the uterus, and the vesiculæ seminales, afford proofs of this statement. It appears, indeed, on the first view, that a cerebro-spinal nerve, when it has numerous communications with the sympathetic, loses its voluntary power; as an instance of this, the lower part of the vagus might be adduced. The motions of the œsophagus are involuntary, although those of the pharynx are subject to the will. It is doubtful, however, whether the motor nerves of the œsophagus be derived from the vagus itself. The urinary bladder receives nerves of two kinds,—branches from the sacral plexus, and others from the hypogastric plexus of the sympathetic. This agrees with its observed functions. The influence of the will over the bladder is very slight.

On the other hand, all muscles which receive nerves from the cerebro-spinal system only are capable of voluntary motion. The small muscles of the ear, in some individuals at least, as in myself, can be moved voluntarily. The cremaster, a prolongation of the obliquus internus and transversus abdominis muscles, can likewise be made to act voluntarily in some persons, although very many persons have no power over it.

The supposition that the admixture of fibres of the sympathetic may remove cerebro-spinal nerves from the influence of the will, seems opposed to one of the fundamental principles of physiology, that of the insulated course and action of the nervous fibres in the peripheral part of the nervous system. The more probable cause of the involuntary action of parts supplied by cerebro-spinal nerves (as the vagus), is, that the motor fibres of such nerves do not reach the centre of volition in the brain, but are excited to action by a reflex influence in the spinal cord. The movements of the pharynx, as well as those of the œsophagus, are involuntary and reflex in their nature.

II. *The parts which are supplied with motor power by the sympathetic nerve still continue to move, though more feebly than before, when they are separated from their natural connections with the rest of the sympathetic system, and wholly removed from the body.*—Thus the heart, after it is taken from the body, continues to beat for a considerable time,—in reptiles and Amphibia for hours; and the peristaltic motions of the intestines continue under the same circumstances. The separated oviduct of a turtle has been seen to contract and expel its contents.

III. *Hence all the parts endowed with motion, and supplied with nerves from the sympathetic, are, in a certain degree, independent of the brain* *and spinal cord.*—The extent to which this is the case has been investigated at page 202. We may mention here as a principal result, that not merely the heart continues to beat feebly for a long period after the destruction of the brain and spinal cord, but that there are well confirmed accounts of embryos in which the brain as well as the spinal cord have been slowly destroyed by disease during the life of the fœtus.*

IV. *The central organs of the nervous system can, however, exert an active influence on the sympathetic nerves and their motor power.*—It results from the experiments of Dr. Wilson Philip and others, detailed at page 205, that the motions of the parts supplied with nervous influence by the sympathetic, do not immediately cease on the sudden destruction of the brain and spinal cord; but that, nevertheless, the character and rapidity of the heart's beat may be influenced by inflicting injury or irritation on the brain and spinal cord previously in an unimpaired state: thus, Dr. Philip states, that, by dropping alcohol and infusion of tobacco upon the brain of animals, he has caused acceleration of the motion of the heart. The influence of the passions is much more evident.

V. *The experiments of Dr. Philip tend to show, also, that distinct parts of the sympathetic, and the movements dependent on them (those of the heart, for example), do not derive their nervous influence exclusively from distinct regions of the brain and spinal cord; but, on the contrary, that the brain and the whole spinal cord, or every part of it, can exert an influence on the motions of the heart.*—Valentin (*De Function. Nervor.* p. 66,) has collected the observations of various authors on the influence of the central organs of the nervous system on the movements of the different internal viscera, and from a comparison of them with his own experiments on the origin and course of the motor fibres of those viscera, has deduced the conclusion, that the cerebellum, medulla oblongata, and cervical portion of the medulla spinalis, have a special relation to the motions of the heart, and also to those of the pharynx, stomach and œsophagus; that the middle and inferior dorsal, and the lumbar portions of the cord, have the same relation to the motions of the large intestines; and the lumbar part of the cord to those of the bladder. A German physician, Dr. Budge, has recently (in *Müller's Archiv. for* 1839, p. 389,) asserted that the centre of motor influence for the intestinal canal lies in the corpora quadrigemina and corpora striata. By irritating those parts of the brain in a dog, he was able to give rise to increased activity of the peristaltic movements.

Having divided the splanchnic nerve in a rabbit, I laid the end of the distal portion on an insulating plate of glass, and galvanised it by means of a battery of sixty-five pairs of plates. Increased peristaltic movements of the intestines ensued, whence it might be inferred that this nerve exerts an influence on the whole intestinal canal, and not on one distinct portion of it. The result was the same from the application of caustic potash to the cœliac ganglion in a rabbit, in which the intestines were laid bare, and in which the increased peristaltic movements excited by the first exposure to the air had again subsided and become very feeble; the movements were, on the application of the potash, immediately rendered very lively.

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* See page 204; and Eschricht, über Gesichts-verdoppelung mit Mangel von Gehirn and Rückenmark. Müller's Archiv. 1834, p. 268.

VI. *The movements excited in organs which are under the influence of the sympathetic nerve, by irritation applied to them or to their nerves, are not transitory and momentary contractions; they are either enduring contractions, or they consist of a long-continued modification of the ordinary rhythmic action of the organ: hence, in these organs, the reaction consequent on the irritation is decidedly of longer duration than the action of the stimulus.*—The motion of the nervous principle in the sympathetic nerve then is slow, and its rate capable of being measured. The abdomen of an animal being laid open, if the intestine be irritated at any point either by a chemical or mechanical stimulus, or by galvanism, contraction of the intestine ensues very gradually, and frequently attains its greatest degree when the exciting cause has long ceased to act. The same takes place in the heart in a different manner: instead of a persistent, not periodic contraction, the momentary application of a stimulus to the heart excites a continued series of periodic beats.

VII. *The immediate cause of the involuntary motions, and the cause of their type, lies neither in the brain nor in the spinal cord, but in the sympathetic nerve itself; even the influence of the ganglia is not necessary; the branches of the sympathetic going to an organ may be entirely removed, the twigs distributed to the substance of the organ only being left, and the motions will be maintained as before, the reciprocal action between the muscular fibres and these ultimate nervous twigs being apparently adequate to their production.*—It is a well-known fact, that the heart removed from the body of an animal, and emptied of blood, continues to contract rhythmically in the frog for several hours; which alone proves that the cause of the rhythm of its contractions cannot be the alternate influx and expulsion of the blood, but must reside in the organ itself.

VIII. *Although from the foregoing observations it is certain that the extreme minute branches of the sympathetic have still the power of regulating the movements of the parts not subject to the will, yet it is not less true that both the brain and spinal cord, and the ganglia themselves, when in a state of irritation, exert an influence on these movements as long as the contractile organs are connected with them through the medium of the nerves. The brain and spinal cord are, however, also to be regarded as the source of the power of the sympathetic itself, which would without them become exhausted.*—We know that every passion of the mind affects the heart's action, and the motions of the intestines are modified by irritation of the spinal cord. In paralytic affections of the spinal cord, again, the movements of the intestines become sluggish. Irritation of the ganglia themselves likewise affects all the nerves which issue from them to be distributed to parts endowed with involuntary motion.

IX. *It results from the facts already stated that the sympathetic nerve is charged as it were with nervous power by the brain and spinal cord, which may be regarded as the sources of nervous influence; but that,* *when once charged, it continues to emit this influence in the manner peculiar to itself, even when the further supply is for a time diminished. This affords an explanation of a part of the phenomena of sleep.*

X. *The influence of narcotics locally applied to the sympathetic nerve does not extend to the distant organs which the nerve supplies; but these organs may be paralysed by the direct narcotisation of the minute nervous fibrils which are distributed in them.*—In this respect the sympathetic resembles the cerebro-spinal nerves, which are deprived of their excitability by a narcotic substance only in the part where it has actually touched them. But with reference to the action of narcotics on the organs under the influence of the sympathetic, there is observed in the case of the heart a remarkable, and at present inexplicable difference between the external and internal surface of the organ. If a narcotic, such as pure opium, or extract of nux vomica, is applied to the external surface of the heart, it produces little or no effect, or, at all events, a very slow one; the rhythmic motions of the heart of the frog, removed from the body and thus treated, continue for a very long time; but if a small quantity of opium or extract of nux vomica be brought into contact with the inner wall of the ventricle, its movements are permanently arrested, frequently in a few seconds after the application of the poison. Of this fact, first observed by Dr. Henry, (*Edinb. Med. and Surg. Journ.* 1832,) I have satisfied myself by repeated experiments on frogs. It is another proof that the motor power of the muscles is dependent on a reciprocal action between them and the nerves, and not a property of the muscular substance alone.

XI. *The laws of reflection stated in the third chapter of this section prevail likewise in the actions of the sympathetic nerve; strong impressions on parts supplied by the sympathetic nerve may be propagated to the spinal cord, and give rise to motions of parts which derive their nerves from the cerebro-spinal system.*

XII. *Impressions on parts of which the nerves are derived from the sympathetic are communicated to the spinal cord and brain, and excite the motor influence of the sympathetic nerve by reflection, although the reflex action is here less marked than in the case of the cerebro-spinal nerves.*—We have an instance of this in the frequent necessity to pass the urine, or, in other words, the more active contractions of the bladder when the urine is of an irritating quality; for in this case the irritant does not act immediately on the muscular coat of the bladder, but upon the sensitive nerves of the mucous membrane.

XIII. *Reflected action of the sympathetic, from an impression communicated to the spinal cord by cerebro-spinal nerves, is a more frequent occurrence.*—As instances of this we may mention the effects on the heart's action of strong pleasurable or painful sensations of the skin; the movement of the iris from impressions on the optic, auditory, and fifth nerves; and the contraction of the seminal vesicles from irritation of the sensitive nerves of the penis.

XIV. *Can reflex phenomena be produced in the sympathetic nerve through the influence of the ganglia, and independently of the brain and spinal cord?*—This interesting question cannot at present be decided.

XV. *We are at present entirely ignorant as to whether irritation in* *one organ can, through the medium of the sympathetic nerve, give rise to movements in another;* since all the sympathetic phenomena of this kind can be explained on the principle of reflection from the brain and spinal cord.

XVI. *It is not proved, (and several facts have been observed which are opposed to the belief,) that the ganglia can exert an insulating action so as to impede the transmission of motor influence from the brain and spinal cord.*—It is not voluntary influence, but motor influence generally, which is here referred to. Every one is aware how readily and quickly an impression on the brain and spinal cord influences the whole sympathetic system; how quickly a mental emotion alters the heart's action, and gives rise to movements of the intestines, together with borborygmi; how a hysterical fit, in which the central organs of the nervous system are affected, terminates with a rumbling of air in the intestines.

XVII. *It is not certain that the ganglia are the cause of the parts supplied by the sympathetic nerve being withdrawn from the influence of the will.*

XVIII. *In certain organs, which are subject to the influence of the sympathetic and of the spinal nerves at the same time, a voluntary influence seems to be exerted only after the long continuance of a centripetal or sensitive impression.*—The urinary bladder presents this phenomenon. The relation in which this organ stands to the brain and spinal cord is very enigmatical. It receives nerves entirely of the sympathetic nature from the hypogastric plexus; and also nerves not of this system, namely, branches from the sacral nerves. It appears to be, under ordinary circumstances, wholly withdrawn from the influence of the will: and nevertheless, when distended, we are able merely by a voluntary effort, and without any aid from the diaphragm and abdominal muscles, to expel the urine. E. H. Weber (*Hildebrandt's Anatomie*, t. iii. p. 354,) likewise admits that the bladder is in some degree subject to the influence of the will.

XIX. *Many parts which are supplied by the sympathetic nerve are indeed capable of involuntary motion only, but become associated with the motions of parts subject to volition, a part of the voluntary motor influence being communicated involuntarily to them, just as in the associate motions of voluntary muscles.*—The heart itself appears to have motor influence imparted to it in this way during strong muscular efforts of the body.

The remarkable phenomenon of the acceleration of the heart's action in voluntary muscular exertions has never been satisfactorily explained. It has been said that, under these circumstances, a larger quantity of arterial blood is required, and that on this account the heart must propel the blood more quickly through the lungs; but it does not follow that, because there is greater need of aeration of the blood, the motion of the heart should be modified in accordance with this end. The phenomenon has been accounted for, again, on the supposition that the passage of the blood through the heart and lungs is disturbed in consequence of the obstruction to the general circulation caused by the contractions of so many muscles; the acceleration of the heart's action takes place, however, when the lower extremities merely are used, as in ascending mountains, running, &c. Now, we cannot perceive how in the latter case the passage of the blood through the lungs and heart can be obstructed; for, though by the constant contractions of the muscles of the lower extremities the circulation is impeded in them, the blood which is not able to pass through the capillaries of these limbs will not reach the heart, and hence cannot accumulate there. The effect can be no more than that of the application of a tourniquet to both thighs by which the circulation in the lower extremities is impeded, but by which nevertheless no acceleration of the heart's action is induced. It is possible, therefore, that this phenomenon, which is so remarkable in persons in a state of nervous debility, may be an associate action dependent on the communication of the nervous principle from the highly excited spinal cord to the sympathetic nerves. Since, however, this explanation cannot be regarded as strictly proved, and is merely supported by analogy with certain facts, it must at present be received merely as a suggestion for further inquiry.

XX. *The motions of organs which derive their nerves from the sympathetic system, have a peristaltic type. The motions are progressive in a certain direction, and the course which they take is dependent not merely on the brain and spinal cord, but likewise on the nerves of the organs themselves.*—The cause of the peristaltic type is wholly unknown. The contractions of the intestinal canal, succeeding each other like waves from above downwards, a second commencing before the first wave has traversed the whole intestine, are well known. This phenomenon is not confined to the intestine; the ductus choledochus also presents vermicular successive contractions, and even in the heart the motions are evidently of the same character.

The explanation of the regular succession of the motions in these organs is one of the most difficult problems in physiology, and has not hitherto been made the subject of any consideration.

b. Of the sensitive functions of the sympathetic nerve.

I. *The sensations in parts, the nerves of which belong to the sympathetic system, are faint, indistinct, and undefined; distinct and defined sensations being excited in them only by violent causes of irritation.*—The faint and undefined character of the sensations may perhaps arise from the small number of sensitive fibres distributed to the parts supplied by the sympathetic nerve.

II. *The sensitive impressions received by the sympathetic nerve, although conveyed to the spinal cord, may not be perceived by the sensorium, the organ of consciousness.*

III. *The impressions which give rise to reflex motions, when conveyed to the spinal cord by the sympathetic nerve, are, in most instances, not productive of sensations; while those impressions which are received by cerebro-spinal nerves always give rise to sensations.*—This is true at least of the majority of cases. Irritation in the stomach, intestine, kidneys, uterus, or liver, which excites vomiting, does not affect the sensorium so as to produce real sensation. In all cases of reflex actions, on the contrary, which are excited through the medium of cerebro-spinal sensitive nerves, the exciting impression gives rise to a distinct sensation. Irritation of the mucous membrane of the larynx, trachea, or lungs, gives rise to a reflected action of the spinal nerves, so as to produce coughing; but a distinct sensation is induced by the irritation. The tickling of the fauces, which excites vomiting, is at the same time productive of a distinct sensation. Distinct sensation attends likewise the irritation of the nostrils, which induces sneezing, and the action of light on the retina, which causes the contraction of the iris, or which, in other cases, causes sneezing.*

IV. *The ganglia of the sympathetic nerve do not prevent the transmission of centripetal actions in that nerve to the spinal cord; they have not an insulating power over its centripetal currents.*—This must be inferred from the facts stated in the foregoing paragraphs; for since the irritation of the sympathetic nerve, which excites vomiting, although it does not give rise to true sensation, is propagated to the spinal cord, the ganglia cannot exert an insulating power over those centripetal actions. That such is the case, however, is proved by a direct experiment, which has been frequently mentioned, that of irritating the splanchnic nerve with a needle in a rabbit, the abdominal parietes of which have been completely divided, when, in many instances, a contraction of the abdominal muscles ensues at the moment of each application of the needle. The ganglia of the main cord of the sympathetic, from which the splanchnic nerve arises, cannot, therefore, have the power of arresting the transmission of impressions from the sympathetic nerve to the spinal cord: and the experiments of Volkmann on decapitated frogs prove the same fact with reference to the ganglia of the abdomen; for, by irritating the intestinal canal and other organs supplied by the sympathetic nerve, he gave rise to very extensive reflex movements of the trunk.

V. *The ganglia are likewise not the cause of the impressions on the sympathetic nerve being unattended with true sensation.*—This also results from facts already detailed.

VI. *In many cases, irritation of a violent nature in organs supplied by the sympathetic nerve, gives rise to sensations in those parts; in other cases, the irritation being less violent, the sensations in the parts affected are indistinct, while distinct sensations are present in other parts supplied with cerebro-spinal nerves.*—We have examples of cases of the first kind in inflammations of the intestinal canal and liver; of those of the second kind, in the troublesome itching which is observed to affect the nose and anus in affections of the intestinal canal,—for example, when they are infested by worms; and at the glans penis in chronic diseases of the kidneys and bladder; while frequently no distinct sensations are perceived at the actual seat of irritation. The pains which are sometimes felt in the upper extremities in diseases of the heart, and in the shoulder in diseases of the liver, are also cases of the latter kind. They are instances of the radiation of sensations wholly analogous to the phenomena described as the results of the radiation of sensations in cerebro-spinal nerves.

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* The movements of the œsophagus in deglutition would appear, from Dr. Reid's experiments, to be owing to a reflex action, excited through the medium of a cerebro-spinal nerve, though unattended with sensation.

VII. *The secondary sensations in cerebro-spinal nerves, consequent on irritation of branches of the sympathetic, occur especially at the extreme parts of the organs affected.*—Thus we have itching of the nose from the irritation of worms in the intestinal canal, itching of the anus from irritation of worms in the large intestine, itching and pain in the glans penis from disease of the kidneys and urinary passages.

VIII. *That the ganglia exert a reflex action in the production of the sympathetic sensations is not proved, and many facts are opposed to the idea of their having such a function.*—The secondary sensations in cerebro-spinal nerves have been commonly attributed to connections of the sympathetic with those nerves; and great influence has been ascribed to the ganglia of the sensitive roots of the spinal nerves, through which the primitive fibres of the roots of the sympathetic as well as those of the cerebro-spinal nerves pass. But from various observations it may be gathered that the theory of the reflected sensations excited by impressions on the sympathetic, is still very obscure, and that, at all events, the mode of accounting for them is a subject of doubt.

c. *Of the organic functions of the sympathetic nerve.*

We are most unacquainted with the laws of the organic actions of the sympathetic nerve; for we have but just learnt that there are in all nerves, even in the cerebro-spinal, peculiar grey fasciculi, or organic fibres, on which depend the organic actions of the nerves in secretion and in nutrition. We have now to inquire whether in these nerves the motion or oscillation of the nervous principle can be propagated only in the centrifugal direction from the trunks and ganglia to the branches, or in the contrary direction also; or whether the action of the nervous principle in them can be exerted in all directions, a particular fibre of these nerves being capable both of transmitting a vivifying influence to a gland, and of exercising a reflex action so as to communicate the irritation in one gland to other organic nerves. It would be desirable also to know whether the organic nerves are, by virtue of their anastomoses, enabled to re-act on each other in such a manner that increased secretion from a whole surface may be excited by irritating one point, or whether all such reflex actions are effected through the medium of the spinal cord. The facts known relative to this subject admit of two explanations, and it cannot be determined with certainty which is the correct one. There are certain cases, however, in which either one or the other theory is more probable.

I. *When, in consequence of impressions on sensitive nerves, secretions take place in distant parts, the brain and spinal cord are probably the medium of communication.*—The cases of sympathetic affections of organic nerves here alluded to are very frequent. Impressions on internal mucous membranes—for example by drinks—frequently give rise immediately to a general sweat. Violent im-

vegetative influence is distributed to the different organs.—Inflammation of the eye, and even the general phenomena of impaired nutrition, have been observed to follow injury of the first cervical ganglion.

V. *This radiating influence of the ganglia appears to be in a certain degree independent of the brain and spinal cord*, since the embryo may be developed while the brain and spinal marrow are destroyed. (See *Müller's Archiv.* 1834, p. 286.)

VI. *It appears, however, that the brain and spinal cord are the main source whence the power of the organic nerves is gradually renovated, since certain affections of the brain and spinal cord, attended with paralysis, are likewise productive of atrophy.*

In concluding our inquiry respecting the sympathetic nerve, we can but lament the obscurity in which much regarding it is involved. We think, however, that we have shown how investigations on this subject must be prosecuted; and that, by applying the laws governing the action of cerebro-spinal nerves to the sympathetic, much light has been thrown on the properties of this nerve, of which M. Magendie seemed to think so little known that he hesitated to regard it as a nerve.

CHAPTER VI.

OF SYMPATHIES.

In the preceding Chapters so many forms of sympathetic phenomena have been shown to depend on known laws of action of the cerebro-spinal nerves, independently of the sympathetic, that the latter nerve appears now to have little share in their production. The phenomena of the radiation and coincidence of sensations, of the associated and the reflected motions, are independent of the action of the sympathetic, and comprehend by far the greater part of the sympathetic phenomena formerly attributed to its influence.

We will now reconsider the sympathies under more general physiological points of view.

The sympathetic relations of the different parts of the system may be arranged under the following heads.

1. *Sympathies of the different parts of one tissue with each other.*

This is one of the most frequent kinds of sympathy. When different parts of a tissue suffer by consent one with another, the secondary affection is ordinarily of the same kind as the original one.

a. Cellular tissue.—There is a great tendency in the cellular tissue to the extension of any particular state from one part through all its prolongations. The diseases of the cellular tissue,—emphysema, œdema, induration, fatty degeneration, inflammation, and suppuration,—afford examples of this tendency. They often spread over large tracts between the muscles, vessels, and aponeuroses, following merely the connections of the interstitial cellular tissue. Hence it is that a knowledge of the natural boundaries of the cellular membrane, namely, the fasciæ, is so important in forming our judgment of suppurations in it.

b. Skin.—Although there is a marked sympathy between the skin and internal organs, yet between the different parts of the skin itself there does not appear to exist any great reciprocal influence. Simple inflammation of the skin may be confined to one part. But the skin may become the seat of extensive exanthematous inflammation, acute as well as chronic, from its having, by virtue of its office of a secreting organ, a certain affinity for morbid matters circulating in the fluids of the body. It sympathizes much more frequently, however, with internal parts, for which it forms the common exterior envelope. Instances of such sympathies will be given hereafter.

c. Mucous membranes.—In the mucous membranes there is, it is well known, a great tendency to the communication of a particular state of one tract to others with which it is continuous, as, for instance, in catarrh.

d. Serous membranes.—A primary affection of one serous membrane is often followed by a similar affection of all the others. Thus, hydro-thorax frequently supervenes to ascites; all cases of dropsy affecting different parts are not, however, examples of sympathy. Dropsy frequently arises from the introduction of morbid matter into the blood in several parts simultaneously, or even from obstruction to the circulation in one important organ. In these cases, therefore, the simultaneous affection of the different serous membranes is owing, not so much to sympathy of the membranes themselves, as to the circumstance of the original cause having an extensive sphere of action.

It is really owing to sympathy, however, when, in consequence of inflammation of one serous membrane, others become inflamed. Thus, sometimes inflammation of the peritoneum is followed by pleuritis and arachnitis.

e. Fibrous membranes.—There is such a close sympathetic connection between the fibrous membranes, that a local lesion very frequently induces an extensive and violent affection of them. A local rheumatic affection is very prone to extend to all the fibrous tissues connected with its original seat, and even to change its locality; always following, however, most readily the connections of the fibrous membranes. Injury of the ligaments, aponeuroses, and fibrous ligamentous tissues of the foot or hand, frequently gives rise to extensive inflammation, swelling, and pain, which spread from the first point of irritation over the sheaths of the muscles, and sometimes attack even the periosteum.

It may be inferred that the nerves have a share in the sympathies of the fibrous membranes, partly from the presence of organic nerves accompanying the vessels in all vascular tissues, and partly from the actual existence of nerves in the dura mater. Nerves have been seen in the dura mater by Comparetti, Arnold, Schlemm, Bidder, and myself: they are in part referable to the system of organic fibres.

f. Bone and cartilage.—Instances of sympathy in the osseous system are rare. In many diseases, as in rhachitis and secondary syphilis, the osseous tissue throughout the body is affected, but these structural diseases can scarcely be arranged among the sympathies; there is here general irritation, with morbid formation of the osseous matter. Distinct examples of sympathy, however, occur also in the bony tissue. Thus, when an irritating influence acts upon the surface of a cylindrical bone, the inflammation which ensues is seldom confined to the surface, but affects the whole thickness of the bone, even to the medullary membrane: the texture of the bone becomes changed in its whole thickness. So likewise, when the medullary membrane of a bone is destroyed, the bone becomes inflamed and swelled internally, and also externally, to its very surface. We are at present unacquainted with the nerves of the bones, but must presuppose the existence of organic nerves accompanying the vessels in them, as in all vascular parts.

g. Muscle.—Muscle has been supposed to enjoy, in a high degree, the property of being excited by sympathy. In proof of this it has been stated that the irritation which causes the contraction of one muscle, is frequently attended with a number of sympathetic actions of other muscles; but here the sympathy is not a property of the tissue itself, but of the motor nerves: a muscle of which the nerve is cut off from the rest of the nervous system is, it is true, still irritable, contracting under the influence of an external stimulus; but the irritation is never communicated to other muscular parts,—no sympathetic motions ensue.

The sympathetic convulsions of the muscular system are, therefore, not properly sympathies of the muscular tissue, but nervous sympathies. The remaining small number of morbid actions which occur in muscles, as inflammation and suppuration, are always limited in extent, and do not spread beyond the original seat of the irritation, as in other tissues. In addition to the very rare inflammatory affections of muscle, its degenerations, and the spasmodic affections, scarcely any other disease is known to attack this tissue. It is evident, from a consideration of all these facts, that in the muscular tissue no very great sympathy prevails, either between its different parts, or between it and other tissues.

h. The lymphatic system comprehends the lymphatic vessels and glands.

Diseases of the lymphatic system are very rarely local. Affections originally seated in the lymphatics, and not sympathetic of diseases of other organs, usually affect them generally, constituting a morbid diathesis. Some diseases, indeed, as scrofula, seem to be confined nearly entirely to the lymphatic system. A state of irritation, which is at first local, rapidly spreads in these vessels by sympathy. When a lymphatic gland becomes inflamed in consequence of external irritation, the surrounding glands soon become affected; they become swollen, if not actually inflamed. Many primary irritations of the lymphatics are produced by irritating substances (poisons) absorbed into them. The inunction of mercury at one part of the surface often gives rise to extensive irritation of the lymphatics, and the glands of different parts of the body become simultaneously affected. Inflammation of the lymphatics from the local action of a poisonous substance rapidly extends to all the lymphatics in the limb; and in such cases the skin is everywhere traversed by red lines, indicating the course of the inflamed vessels.

Of equally frequent occurrence are instances of the sympathy of the lymphatic vessels with lymphatic glands. One of the most common symptoms in structural diseases of the great viscera, is enlargement of the lymphatic glands in their neighbourhood.

Sympathetic enlargement of the lymphatic glands is equally frequent in inflammatory affections of a neighbouring part.

These sympathetic enlargements of the glands differ chiefly from the original affection in disappearing as soon as the disease of the organ primarily affected is removed; in being chronic when excited by a chronic disease, acute when the primary disease is acute; and, lastly, in consisting simply of tumefaction, generally without any other change from the natural state of the tissue.

We may state generally that an extensive irritation of the lymphatic system may be excited from any point of the surface which is supplied with lymphatic vessels. The exciting cause may either be the actual introduction of an irritating matter, or a lesion unattended by absorption; for example, a mechanical injury, or a burn. Hence, we see that for the excitement of this sympathy it is, at least, not indispensable that a morbid matter be actually carried along the vessels. The irritation of the lymphatics may be excited, too, by original irritation of an internal surface of the body, as well as by lesion of the external surface, when a corresponding series of phenomena ensues. Just as inflammation of the skin from a burn is followed by irritation of the surrounding lymphatics, extending to the nearest lymphatic glands, so inflammation of the mucous membrane of the intestinal canal, when it continues for any length of time, as in typhus, induces inflammation of the lacteals and mesenteric glands,—those lacteals and glands, namely, which correspond to the inflamed part of the intestine.

Sometimes the lymphatics, as well as the veins, coming from a suppurating part, contain pus. The corresponding lymphatic glands also occasionally suppurate. It would be an error to infer that the pus in these cases had been absorbed by the lymphatics; it is produced in the vessels themselves by the inflammation which has extended into them, just as the pus in the veins of the stump of an amputated limb is produced by inflammation of their coats. The inflammation and suppuration of the mesenteric glands, consequent on ulceration of the intestines in typhus, afford us a distinct proof that in this case, at least, the pus is formed in the absorbent vessels and glands themselves.

i. Blood-vessels.—When it is remembered that the sympathy of the pulse with the diseases of individual organs depends on a sympathy of the heart, rather than of the arteries themselves; and when, moreover, it is taken into consideration that the local diseases of arteries, such as inflammation and dilatation, are in a great measure limited to the point to which their exciting cause was applied, and have no tendency to spread; we are justified in the conclusion that the sympathies of arteries are in general inconsiderable: we must, at least, adopt this opinion with regard to the coats of the larger arteries and their branches. But we cannot doubt that the nervous system may exert an influence over the state of the arteries independently of the heart; this influence is seen in the varying state of turgescence of the skin during mental emotions,—the local congestions and succeeding collapse which are observed to occur in different parts of the surface under such circumstances.

In cases of a general affection of veins, it is difficult to determine whether this has originated at one point, and gradually spread from sympathy of tissue, or whether the immediate cause of the disease has acted simultaneously on a great extent of the venous system. It is, however, a character of this system of vessels, that its diseases are, generally, not local.

We have direct proof of the extended sympathy of the veins in phlebitis, which being excited at any point, by causes capable of giving rise to inflammation, extends so rapidly, that in a short space of time all the venous trunks of the limb become affected.

k. Glandular tissues.—Although certain diseases, as scrofula and cancer, attack principally the glandular tissue, yet these general affections of the glands cannot be attributed to sympathy, but arise from the nature of the diseases themselves, which have an especial tendency to affect glandular structures; and their extension is not so much the consequence of an original local irritation, propagated by sympathy, as of a general morbid disposition of the tissue developed to a complete disease under the influence of local irritation. There is no doubt, however, that when a disease commences in a single gland, it will, from the sympathy of the different parts of the gland, more readily affect the whole of its substance than other surrounding textures. The following are instances, however, of sympathetic irritation of glands.

All secreting organs, just as they reflect irritation in themselves upon their efferent ducts, are also sympathetically affected with irritation when their efferent ducts are first affected; thus the presence of food in the mouth gives rise to an increased flow of saliva from the salivary glands, the presence of a sound in the bladder excites an increased secretion of urine(?), irritation of the glans penis an increased secretion of semen, and irritation of the mucous membrane of the eye a more abundant secretion of tears. Thus also, while the food is in the stomach, the bile flows into the small intestine in small quantity; but, when the chyme has come into contact with the mucous coat of the duodenum, it is poured out in much greater abundance; while, during fasting, on the contrary, the amount of bile excreted is very scanty.*

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* The facts considered in this section have been elucidated by the principles of physiological anatomy, chiefly through the labours of Bichât, whose work on general anatomy contains more of the true principles of general pathology than most of our treatises on that subject.

It is difficult to account for the sympathy evinced by different parts of a tissue for each other. It has been supposed to be independent of nervous action, and to be owing to the identity of structure and continuity of the tissue. But can inflammation, for example, really spread in a tissue by this kind of contagion? Can the component substance of a tissue, independently of nervous influence, by a kind of affinity of its different parts, communicate a state of irritation from one point to those contiguous? We cannot decide this question. Other physiologists have attributed these sympathies of a single tissue to the influence of the nerves, inasmuch as mucous membranes which are not anatomically connected, and serous membranes which do not communicate in any way, present phenomena of sympathetic consent. But still another explanation of such cases might be offered, namely, that all the phenomena are owing to a noxious matter absorbed into the blood or generated in it, which has an affinity for all mucous or all serous membranes, &c. The nerves are, however, evidently engaged in the cases of the extension of sensations over the different parts of the same tissue; but whether by virtue of a connection of their peripheral extremities, or through the intervention of the central organs of the nervous system, is another question.

II. *Sympathies of different Tissues with each other.*

This second form of sympathy is of much less frequent occurrence than the first. Ordinarily a disease has a much greater tendency to affect the same tissue in a different organ from that first affected, than to be communicated from one tissue to another even in the same organ. The mucous coat may take on a morbid secreting action, without the muscular coat suffering; the serous covering of the heart may be the seat of disease, while the muscular substance under it remains healthy; the muscular coat of the intestinal canal may be affected with spasm, the mucous and serous coats remaining in their normal state; and the serous tunic of an organ may secrete a watery fluid without the other tunics being affected. There are instances, however, of sympathy between different tissues. It is here to be observed, that when different tissues sympathise with each other, the phenomena vary in them according to the properties of each; while in the sympathy of different parts of the same tissue, the secondary affection is ordinarily identical in its nature with the original one. Inflammation alone manifests itself with the same characters even when it affects different textures. The principal examples of this second form of sympathy are the following:—

1. *Between the skin and mucous membranes.*—These textures very frequently sympathise. Many diseases of the mucous membranes, particularly inflammation and increased secretion, are frequently excited by the action of a noxious influence of the skin, and *vice versâ.* The action of cold upon the skin gives rise to inflammation of the lungs, throat, or intestines, or to catarrhal affections of these or other mucous membranes; the mucous membrane of that organ being always attacked, which, from idiosyncrasy of

the individual, is more disposed to disease than the skin. On the other hand, a diseased state of the mucous membrane, of that of the stomach, for example, induces an altered condition of the secretion of the skin, of the circulation in it, and of its colour. Owing to the sympathy of the mucous membranes with the skin, we can arrest hemorrhages from the former by the application of cold to the latter structure.

2. *Between the skin and serous membranes.*—The effusion of a watery fluid from the serous membranes is always attended with diminished secretion from the skin; and suppression of the cutaneous secretion sometimes gives rise, on the other hand, to effusions into the serous cavities, as well when the skin is in a healthy state, as when it is the seat of an exanthematous eruption, whose course is disturbed. Lastly, inflammations of the serous membranes are not infrequently excited by the action of noxious influences upon the skin.

3. *Between the glandular tissue and the mucous membranes.*—I have already mentioned how close a sympathy prevails between the mucous membranes, and the glands which pour their secretion into them. At this we must not be surprised; since the glandular tissue is not merely a development, as it were, of the efferent duct, and this a prolongation of the mucous membrane, but the glands connected with the intestinal canal are originally formed as diverticula from it.

4. *Between the mucous membranes and the serous membranes,* such reaction is of more rare occurrence.

5. *Between the fibrous membranes, as the periosteum, and the cartilaginous and osseous tissues,* there is a very close sympathy. The state of the periosteum determines that of the bone, and *vice versâ.* Inflammation of the periosteum is frequently followed by enlargement of the bone beneath it; and, when swellings of the osseous substance itself take place, the periosteum becomes thickened. Enlargement of the whole thickness of a bone is a result of inflammation of its medullary membrane. Destruction of the periosteum gives rise to external, destruction of the medullary membrane to internal, necrosis. This relation depends principally on the circumstance that innumerable minute vessels are received by the bone both from the periosteum and the medullary membrane.

An observer of the phenomena of disease will easily multiply the examples of sympathy between different tissues. The same explanation is not applicable to all such cases. Secreting membranes by virtue of their influence on the circulating fluids, and independently of the nerves, stand in an antagonistic relation to each other. Other phenomena, in which it is not so much the secretion only, as the whole vital condition of the membranes, which is altered, as in the reaction of the skin and mucous membranes on each other, are rather to be referred to the effects of reflex action of nerves. With respect to the sympathy of the glands and mucous membranes, it is uncertain whether it be owing to reflection, or to the direct action of the nerves on each other, by the intervention of the sympathetic.

The sympathy of the periosteum and medullary membrane with the osseous substance is to be ascribed to vascular communication, and to the sympathy of the vascular tissue common to them.

III. *Sympathies of individual Tissues with entire Organs.*

A disease of an entire organ, into the formation of which a tissue that extends to other parts enters, affects also the prolongations of this tissue; and, on the other hand, the state of a single tissue may modify all the others, which with it form a compound organ. Examples of this kind of sympathy may be found more particularly in the relation existing between the viscera and the skin, the mucous and the serous membranes.

Through the medium of the skin noxious influences may set up disease in any internal organ predisposed to it; and, on the other hand, the application of irritants and derivatives to the skin has an effect on a diseased state of any organ lying near the part irritated. Hemorrhages from internal parts are arrested by the action of cold upon the skin. Lastly, an exanthematous disease may disappear from the skin, and affect an internal organ.

The serous membranes always participate in the condition of the organs to which they give an investment. When the viscera are the seat of structural disease, the serous membranes take on a morbid action, not merely where they cover the diseased organ, but in their whole extent. Thus, organic disease seated in the lungs gives rise to hydrothorax, in the heart to hydro-pericardium, in the uterus and ovaries to ascites, and in the testis to hydrocele. When viscera, of which mucous membranes form part, are diseased, those membranes are always affected in a great extent. Organic diseases of the uterus are attended with leucorrhea; diseases of the lungs, with affection of the bronchi; and structural diseases of the stomach and intestinal canal, are frequently accompanied by obstinate constipation from defective secretion of the intestinal mucous membrane.

The whole system sympathises with the inflammatory state of a mucous membrane; and the surrounding muscles either act with difficulty, as is the case with the pharyngeal muscles in inflammation of the pharynx; or they are affected with spasms, as when irritation of the lungs gives rise to spasmodic action of the diaphragm and intercostal muscles, so as to produce coughing. Mechanical irritation of the mucous membranes has the same effect. Every one must have observed the convulsive actions excited by mechanical irritation of the glottis, the retching from irritation of the mucous membrane of the pharynx; and in the same way irritation of the mucous membrane of the bladder or ureters by calculi, or inflammation of that membrane, gives rise to spasmodic contraction of the sphincter ani, of the sphincter vesicæ, and to drawing up of the testicle by the cremaster.

Of all membranes the fibrous have the least sympathy with other organs, even with the organs which they invest. These fibrous membranes, which have the office of affording protection or attachment to other parts, are in this respect almost insulators. Only inflammation of these membranes can affect the organs which they invest, and can give rise to marked symptoms in them, and this depends on the communication and sympathy of their vessels; thus it is that inflammation of the dura mater is attended with cerebral symptoms.

The explanation of the sympathy of individual tissues with entire organs is to be found partly in the laws of nervous reflection, when the sympathising parts are quite unconnected, and partly in the reaction of communicating vessels, and of the nerves accompanying these vessels in connected parts, such as the uterus and the mucous membrane of the genital organs.

IV. *Sympathies of entire Organs with each other.*

Although it is essential to our ideas of a living organism that the condition of one organ has an influence on that of all the others, yet this influence is manifested principally between the organs of certain systems or groups. The sympathies which fall under this head are the following:—

1. Sympathies between organs which have similar structure and function; as between the different salivary glands, between the heart and blood-vessels, between the stomach and intestines, and between the different central organs of the nervous system.
2. Sympathies between organs which, although of different structure, yet belong to the same system; such as the different viscera of the chylopoietic system (intestinal canal, glands, and spleen), the uropoietic system, the generative system,—the two latter systems reacting on each other,—and the respiratory system of organs (larynx, trachea, and lungs).
3. Sympathies between organs anatomically connected by means of vessels and nerves, as the lungs and heart.
4. The sympathies which connect all important viscera with the central organs of the nervous system. We have instances of such sympathy in the affection of the brain which accompanies inflammation of internal viscera, as the liver, lungs, or intestinal canal; and in the affections of the stomach and liver, which attend injuries or irritation of the brain, &c.

The phenomena of this class are partly owing to the different organs of the same system, or parts anatomically connected, deriving their nervous influence from one and the same source; and partly to the influence of the central organs of the nervous system upon all the organs of the body. The probability of these phenomena being in a greater degree dependent on the central organs of the nervous system than on the anastomoses of the sympathetic nerves, is rendered stronger by the occurrence of sympathies which are quite inexplicable by nervous communication or anatomical connection; such as the sympathies of the mammæ with the genital organs, and of the larynx and respiratory organs with the genital organs at the period of puberty, and in debauchees and eunuchs. The sympathy of the parotid and testicle in the metastasis of inflammation from the we are enabled to stimulate sensitive nerves, which are not directly accessible to us, such as the auditory or optic nerves, by applying the stimulating means to other sensitive nerves which stand in close relation with them, both physiologically and in respect of origin. Thus, we treat partial deafness and imperfect loss of vision by irritants to the skin, &c. By virtue of the reflected action of sensitive upon motor nerves, also, through the intervention of the brain and spinal cord, we are sometimes enabled to remove local paralysis of individual nerves, for example, paralysis of the facial nerve, or ptosis, by irritating the nerves of the face, &c.

III. *Sympathies of the corresponding nerves of the two sides.*—Of this we have instances, particularly in the optic, auditory, and olfactory nerves, and in the ciliary nerves.

When one eye is affected with a disease, and originally but this one, the other is frequently attacked by the same disease. One eye being destroyed by inflammation, the other frequently becomes inflamed and likewise disorganised. Affections of the internal ear are not always confined to one side. Deafness of one ear is often followed by the other becoming deaf also. The sympathies of the motor nerves of the eye, and especially of the ciliary nerves, are sufficiently well known. In the healthy state, the sympathy of the nerves of the two irides causes the pupil to be of equal size, although the action of the external cause determining their contraction is very different on the two sides. The sympathy of the corresponding nerves of the opposite sides is evidenced very frequently in what are called neuralgic diseases,—the painful affections of the nerves. In consequence of painful affection of the nerve on one side of the face, the corresponding nerve of the other side sometimes becomes affected. Toothache from a decayed tooth is not confined to the seat of the irritating cause; the corresponding nerve of the opposite side is occasionally affected.

IV. *Sympathies of motor nerves with each other.*—The extremely frequent phenomena of associate motions, the movements which involuntarily accompany other movements determined by the will, have been treated of at page 533.

V. *Sympathies of sensitive nerves.*—These present themselves principally under three forms, which differ merely in the extent and distance from each other of the parts thrown into consensual action.

a. In the first case, a violent sensation excited at a single spot extends to nerves of the same kind, or to other fibres of the same nerve producing phenomena which have been treated of under the head of the "radiation of sensations," at page 544.

b. In the second case, an affection of one sensitive nerve induces an affection of a sensitive nerve of another kind, but in the same organ. This kind of sympathy is observed principally between the nerves of special sense and the nerves superadded to the organs of sense, for the reception of the general impressions of resistance, warmth, cold, pleasure, and pain. The optic nerve is susceptible of the impression of light; but is not endued with common sensibility, which the eye receives from branches of the fifth, ramifying in the conjunctiva, and from the ciliary nerves. The organ of hearing has, in addition to the auditory nerve, fibres from the facial, the second, and third division of the fifth nerve, and from the ganglion oticum, which are distributed in the mucous membrane of the tympanum; and from these, together with the numerous nerves of the external ear and external meatus, the common sensibility of the organ of hearing is evidently derived. The nose is not only the seat of the sense of smell, the function of the olfactory nerves, which, according to Magendie, are devoid of common sensibility, but is very susceptible of other sensations, such as resistance, warmth, cold, tickling, pain, &c. which are due to the presence of nasal branches of the fifth nerve. It is very well known that the tongue has not only the sense of taste, but also the sense of touch.

Now, the nerves of special and those of common sensation in the organs of sense have a marked influence on each other. The blindness which sometimes follows injury of the frontal nerve has been thought to be an instance of this. It has been imagined that the effect of the injury of the frontal nerve is propagated backwards to the trunk of the ophthalmic, from the nasal branch of which the ciliary ganglion derives its longer root. But the ciliary nerves can influence the power of the iris only, and not that of the retina, with which they are in no way connected. It appears to me much more natural to suppose that the blindness consequent on contusions of the forehead is owing to the concussion suffered by the eye and optic nerve. M. von Walther has, I think, gone too far in attributing much influence to the ciliary nerves in the production of amaurosis and amblyopia. In many other phenomena, however, we have indubitable proofs of the sympathy of the different nerves of the organs of sense; for example, in the sensation of tickling in the nose from looking at the sun, and in the sensation of shuddering, and creeping over the surface, excited by certain sounds, &c. The principles laid down in the section on the laws of nervous action do not leave much doubt concerning the explanation of these phenomena. Since communications of the nerves of special sense with the superadded nerves of common sensation, by means of the sympathetic, have not been satisfactorily demonstrated to exist, we must refer the phenomena in question to reflection of the impression in the brain. Tiedemann, (*Zeitschrift für Physiol.* i. 237,) in treating of the sympathies of the organs of the senses, lays stress upon the fact that all those organs receive branches from the sympathetic nerve; this cannot be denied; but, to explain the sympathies of the nerves of special sense with other sensitive nerves, it is necessary, not that the organ generally, which is a part composed of numerous tissues, but that the nerve itself should have such connections with the sympathetic. Such connections have indeed been described. Tiedemann himself saw branches of the ciliary nerves accompanying the arteria centralis retinæ, even as far as the retina; but this does not prove a connection of the optic nerve or of the retina with the sympathetic. Hirzel (*Tiedemann's Zeitschrift*, i. 229,) observed in several cases a connection between the ganglion spheno-palatinum and the optic nerve.

Arnold traced such a twig as far as the sheath of the optic nerve, but denies its connection with the nerve itself. Varrentrapp (*Observ. Anat. de parte cephal. nerv. sympath.* Francof. 1831,) did not see this communicating filament. But even if the optic nerve did really receive a filament from the sympathetic, much would not thereby be explained; for, to establish such a communication as is necessary to explain the sympathies, the communicating thread of the sympathetic must be connected with all the fibres of the optic nerve; its connection with one or a few of these fibres would not be sufficient. The same remarks apply to the organ of hearing. Koellner, Swann, Arnold, and Varrentrapp have observed a connection between the facial and the acoustic nerve, within the meatus auditorius internus. According to Arnold, (*Der Kopftheil des veget. Nervensyst.* Heidelb. 1831, p. 83,) the communication is twofold: one is through the medium of the sympathetic nerve. A fibre derived from the sympathetic leaves the facial to join the acoustic nerve, and in the calf forms a small ganglion at the bottom of the meatus auditorius. This structure, which is very distinct in the calf, appears to me to be destined to convey organic fibres into the interior of the labyrinth. The organic fibres of the tympanic plexus may probably be subservient to the organic functions, such as the secretion of mucus. The second mode in which the facial and acoustic nerves are connected, is by means of a fibre which passes from the smaller portion of the facial nerve to the nervus acousticus. Since at their origin the two nerves are connected by many nervous filaments, this communicating thread in the meatus auditorius may be regarded as a fibre which belongs to the acoustic nerve, but which has thus far accompanied the facial. The ramus acousticus accessorius, derived from the facial in birds and the cyclostomatous fishes, is to be viewed in the same light.

The remarks which we have made regarding the sympathies of the nerves of special sense with the other superadded nerves of the organs of sense, may be applied to the more remote sympathies of these organs with the abdominal viscera. Partial amaurosis, tinnitus aurium, and other symptoms, have been observed accompanying a disturbed state of the functions of the abdominal viscera; and many persons have explained these phenomena on the supposition of the sympathetic nerve having a share in the functions of the organs of sense, although they are much more easily accounted for as the result of the impression made by the disordered viscera upon the brain and spinal cord, and by them reflected upon the organs of sense. These secondary affections of the senses cannot, however, be regarded in this isolated manner; the whole nervous system frequently suffers in such cases; obstinate pains in the head precede or accompany the affection of the organs of sense, or the sensibility of the nerves of common sensation generally is found to have suffered.

Having now considered separately the different forms of sympathy, we must glance at the application which may be made of these views in the treatment of disease.

The principle of the balance of sympathy teaches us how we must avoid aggravating the morbid condition of one organ by the means which we apply to another; but it also teaches us how we may produce a change in the state of one organ directly inaccessible to us by effecting an appropriate change in another. The remedial means which act by virtue of the sympathies of the body have received the names of derivation and counter-irritation, inasmuch as they are intended to remove a certain state in one organ by inducing artificially a change in another. Their mode of action may be thus stated:—

1. Exaltation of the activity of an affected part, by artificially increasing that of the part which sympathises with it.

2. Depression of the irritation of a part, by producing relaxation of the consensual part.

These results may be expected in the highest degree in the sympathies of the nerves, and especially wherever the laws of reflection from sensitive upon motor nerves, by the intervention of the brain and spinal cord, come into play. In the nerves distributed over the whole surface of the skin, we have an extensive field for acting indirectly on the brain and spinal cord. By friction, electricity, moxas, cold baths, and mustard plasters, we stimulate the peripheral extremities of the cutaneous nerves, and indirectly the central organs of the nervous system; by soothing the peripheral nerves in the skin by tepid baths, we allay irritation of the brain and spinal cord.

3. Diminution of a morbid secretion in one part, A, by increasing the secretion of another part, B, or by giving rise to a similar secretion in the second part, B. This mode of action is the reverse of that which takes place in the preceding cases; it is explained by the principle of the antagonism of secretions, laid down at page 451. There is an exception to this law in the sympathy of the different parts of one and the same tissue (see page 578).

4. Diminution of sanguineous congestion in one organ, by exciting congestion artificially in another organ; as in the action of hot foot-baths. This case is similar to the preceding, and is the reverse of the first two, but is explicable on the same principle.

5. Diminution of a certain state, x, in one part, A, by exciting a different state, y, in a second part, B, of the same tissue; a method which we adopt frequently with the best effects. Secretion and inflammation, particularly when seated in a secreting organ, are to be regarded almost as opposite states. Inflammation always arrests the natural secretions. Hence inflammation of the mucous membranes of the fauces is successfully treated by exciting a diarrhœa. The same reaction can be excited between different tissues. A diarrhœa diminishes congestion in the head. This case, however, belongs to the mode of action indicated in paragraph 4.

6. Diminution of a certain state, x, in one organ, by exciting the same state in another organ. This appears to be contradictory to most of the facts established in the foregoing paragraphs, and its explanation is a matter of great difficulty. The production of an inflammatory state artificially in the neighbourhood of an inflamed

art would cause the original inflammation to become increased, ot diminished, particularly if the artificial inflammation were nduced in a part of the same tissue; and, nevertheless, inflammaion of one organ is rendered less active by inflammation being exited in another organ, at a certain distance from the one originally iseased. Ophthalmic affections are treated by exciting inflammaion of the skin at a little distance from the eye.(*a*) Affections of the oints, &c. are treated by counter-irritation of the skin. The success f these methods of treatment seems to prove, that the states of irriation of the capillary vessels of two organs, particularly if in diferent tissues, are not subject to the same relation which we have bserved to prevail so distinctly, in the cases indicated in pararaphs 1 and 2, between peripheral and central parts; and by virtue f which, irritation of the peripheral branches of the nerves does not rrest irritation of the central organs, but induces in them a more ctive state.

SECTION IV.

OF THE PECULIAR PROPERTIES OF INDIVIDUAL NERVES.

CHAPTER I.

Of the Nerves of Special Sense.

THE nerves have always been regarded as conductors, through the edium of which we are made conscious of external impressions. Thus the nerves of the senses have been looked upon as mere pasive conductors, through which the impressions made by the proerties of bodies were supposed to be transmitted unchanged to the ensorium. More recently, physiologists have begun to analyse hese opinions. If the nerves are mere passive conductors of the mpressions of light, sonorous vibrations, and odours, how does it appen that the nerve which perceives odours is sensible to this kind f impressions only, and to no others, while by another nerve odours re not perceived; that the nerve which is sensible to the matter of ight, or the luminous oscillations, is insensible to the vibrations of onorous bodies; that the auditory nerve is not sensible to light, nor he nerve of taste to odours; while, to the common sensitive nerve, he vibrations of bodies give the sensation, not of sound, but merely f tremours? These considerations have induced physiologists to scribe to the individual nerves of the senses a special sensibility to ertain impressions, by which they are supposed to be rendered conuctors of certain qualities of bodies, and not of others.

This last theory, of which ten or twenty years since no one doubted he correctness, on being subjected to a comparison with facts, was ound unsatisfactory. For the same stimulus, for example, electricity, ay act simultaneously on all the organs of sense,—all are sensible

(*a*) See page 451, and foot-note.

to its action; but the nerve of each sense is affected in a different way,—becomes the seat of a different sensation: in one, the sensation of light is produced; in another, that of sound; in a third, taste; while, in a fourth, pain and the sensation of a shock are felt. Mechanical irritation excites in one nerve a luminous spectrum; in another, a humming sound; in a third, pain. An increase of the stimulus of the blood causes in one organ spontaneous sensations of light; in another, sound; in a third, itching, pain, &c. A consideration of such facts could not but lead to the inference that the special susceptibility of nerves for certain impressions is not a satisfactory theory, and that the nerves of the senses are not mere passive conductors, but that each peculiar nerve of sense has special powers or qualities which the exciting causes merely render manifest.

Sensation, therefore, consists in the communication to the sensorium, not of the quality or state of the external body, but of the condition of the nerves themselves, excited by the external cause.—We do not feel the knife which gives us pain, but the painful state of our nerves produced by it. The probably mechanical oscillation of light is itself not luminous; even if it could itself act on the sensorium, it would be perceived merely as an oscillation; it is only by affecting the optic nerve that it gives rise to the sensation of light. Sound has no existence but in the excitement of a quality of the auditory nerve; the nerve of touch perceives the vibration of the apparently sonorous body as a sensation of tremour. We communicate, therefore, with the external world merely by virtue of the states which external influences excite in our nerves.

By the knowledge of the fact just announced, we are led not only to recognise the peculiar qualities of the different nerves of sensation, in addition to their general distinction from the motor nerves; but we are also enabled to banish for ever from the doctrines of physiology a number of erroneous notions regarding the supposed power of the nerves to perform the functions of each other. It has been long known that blind persons cannot recognise colours with their fingers, *as colours:* but we perceive now why it is impossible for them to do so. However acute the sense of touch in the finger of the blind may be rendered by practice, it can still be but the one sense proper to the nerves of the fingers,—*touch.*

The facts which we have considered afford also a refutation of opinions still current, which regard it as possible that the functions of the optic and olfactory nerves, when they are absent, can be performed by the nervus trigeminus.

Some animals, though provided with eyes,—for instance, the mole and *Proteus anguinus,*—have been said to want the optic nerves, the sense of vision being then placed in the ophthalmic branch of the fifth nerve. This statement has arisen, in the case of the mole, from inaccuracy of the anatomical examinations; and the same is the case probably in the Proteus. The mole has an uncommonly small optic nerve, and a very delicate chiasma, as Dr. Henle has shown to me. It has been stated that, in the Cetacea, the office of the olfactory nerve, which, according to Blainville, Mayer, and Treviranus, is

small and rudimentary, (*Treviranus, Biologie,* v. 342,)
by the nasal branches of the fifth nerve. How slight the
this conclusion are, is evident, when we consider that we
e least proof that the Cetacea have the sense of smell.
die (*Journal de Physiologie,* t. iv. p. 169,) imagined that
nd proof of the olfactory nerve not being the nerve of
of this sense being the property of the nasal branch of the
remarked that, after the olfactory nerves had been de-
imals were still sensible to acetic acid, ammonia, oil of
nd oil of dippel; for, when these substances were applied,
d their nostrils with their feet, and sneezed. This proves,
ht* remarks, and as every one must perceive, that the
rves are the nerves of the sense of smell only, and not
mmon sensation; for all the substances which Magendie
re excitants of the common sensibility of the mucous
of the nostrils, derived from the nasal branches of the
flesh of animals excites the sensation of smell only; and
lie confesses, that a piece of meat enveloped in paper and
re a dog in which the olfactory nerves had been destroyed,
ct the animal's attention. That the sense of smell is
en the olfactory nerves in man do not exist, or have been
s shown by the cases related by Rudius, Rolfink, Mag-
ppert, Balonus, Loder, and Serres.† Mery‡ and Berard,
rary, state that they have observed persistence of the
ll with induration of the olfactory nerves, or of the an-
of the brain. But what assurance have we that these
s have not confounded the sense of smell with the com-
lity of the nose?

e of taste appears never to arise as a separate nerve; on
, its fibres seem to be included in other nerves, probably
gual and palatine branches of the fifth; for both the
tongue are endowed with the sense of taste. Cheese
h the palate only, is distinctly tasted. Even the pharynx
f sensations allied to taste, namely, those of nausea.

ste has been observed in cases where the fifth nerve has
n disease.§ Magendie observed the same effect after
lingual nerve; and the experiments of Mayo, and those
self instituted in conjunction with Professor Gurlt and
, were attended with a similar result.

regards the lingual branch of the fifth as a mere nerve
sensation or touch, and the glosso-pharyngeus as the

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unct. primi et quinti paris in Olfact. Organo. Magendie, Journ. t.

Eschricht, loc. cit. and Backer, Comment. ad Quæst. Physiol.

Anat. et Chirurg. par Portal, t. iii. p. 603. Magendie's Journ. t.

m. of Pathol. and Therap. vol. i., and Mr. Bishop in the Medical
l, 1833.

Sperimentali sopra i Nervi. Pavia, 1834. An account of Panizza's
s given by Dr. G. Burrows, in the 16th vol. of the Med. Gaz.

nerve of taste. It appeared to him that taste was not lost after division of the lingual branch of the fifth. The animals in which the experiment was performed, tried to eat bread, milk, and meat, with which colocynth and quassia had been mixed, but immediately rejected them; while, after the glosso-pharyngeus had been divided, they swallowed even bitter substances.

Recent experiments, however, throw doubts upon Panizza's theory.

If taste really remained after the division of the gustatory nerve, it might be due to the palatine branches of the fifth. In experiments instituted by Gurlt, Kornfeld, and myself, the sense of taste remained quite perceptibly after division of the glosso-pharyngeal nerve. Experiments of this kind are attended with difficulty, and are liable to many sources of error. Horses and dogs, if hungry, will eat food impregnated with the most bitter matters, even when all their nerves are in a state of integrity. It is not from the circumstance of their eating or not eating what is bitter, that we can judge of the presence or absence of taste, but from the manner in which they eat it.* The results of Dr. Alcock's experiments also, as well as those of Dr. Reid, were unfavourable to Panizza's theory.

Valentin and Wagner, on the other hand, have adopted Panizza's opinion. In experiments on dogs, Valentin† found that when all the fibres of the glosso-pharyngeal nerve, its pharyngeal as well as its lingual branches, were divided on both sides, the animals showed no sign of retaining taste; while division of the lingual branch of the fifth nerve deprived the tongue of its common sensibility, leaving the sense of taste unimpaired. Valentin also confirms the statement of Wagner, (*Froriep's Neue Notizen*, No. 75, p. 129,) that the parts of the tongue and fauces in which taste resides, correspond with the distribution of the glosso-pharyngeal nerve; these parts are the posterior part of the tongue as far as a line drawn somewhat in front of the foramen cæcum, its margin, and the under surface of its tip, the soft palate, uvula, and arches of the palate, and the superior part of the pharynx. The anterior part of the dorsum of the tongue is very rarely endowed with the sense of taste. In further support of the opinion that the glosso-pharyngeal is the nerve of taste, Valentin refers to the case related by Mr. Noble, in which, one side of the face having lost its sensibility, apparently from some disease of the fifth nerve, the corresponding side of the tongue had also lost the sense of touch, but had preserved that of taste. (*Med. Gazette*, vol. xv. p. 120.) A precisely similar case has been more recently observed by Dr. Vogt. (*Müller's Archiv.* 1840, p. 72.) In other cases, where taste has been lost, together with the sensibility of the tongue, and where the fifth nerve has been found after death involved in some disease, the glosso-pharyngeal having apparently escaped, there is no proof, Valentin remarks, that the part of the central organs from

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* See Kornfeld, De functionibus nervorum linguæ experimenta. Berol. 1836.

† Repertor. 1837, p. 221; and his more recent work De Functionibus Nervorum p. 41, and 116.

latter nerve arises, has not been the seat of an undisco-
n.
;ual branch of the fifth is likewise a nerve of touch, or
ensation; the tongue derives its sense of touch from this
from the glosso-pharyngeal. The division of the lingual
he fifth nerve has been observed both by Magendie, Des-
id myself to be very painful. It is possible that there are
ments for taste and touch associated in it. The chorda
: all events, may be looked upon as destined for common

'ous fibres endowed with the sense of taste may be super-
ry different nerves. In birds the nerve of taste is a branch
o-pharyngeal, in frogs it is a branch of the vagus.
endie (*Journ. de Physiol.* iv. 302,) asserts that he has
r all the senses annulled by the division of the trunk of
rve within the cranium. The loss of vision he inferred
imal not noticing the light of a lamp. But rabbits are
not affected by light, even when the fifth nerve is not
d M. Magendie himself confesses that, when the light of
s allowed to break in where lights had been previously
ne eyelids of the animal closed; and this was seen still
ctly when the light was thrown into the eye through a
Magendie demonstrates by experiment on animals what
o well from the observation of diseases in man, namely,
the optic nerve is paralysed, its function—the perception
not performed by the fifth; but he is of opinion that the
ast an auxiliary to the optic nerve, and necessary for the
nance of the visual function. M. Magendie believes also
n is necessary for hearing.
umstance of an animal not being susceptible of other im-
nmediately after the division of so large a nerve as the
s nothing more than that it has suffered a serious injury.
n fact, that the division of large nerves,—for instance, of
rve,—gives rise to serious symptoms. According to my
fth nerve has no influence either on vision, hearing, or
un epileptic patient, in whom there was inflammation of
l opacity of the cornea on the right side, with loss of
subsequently insensibility of the eyelids, nose, and tongue
e side, deafness of the right ear, and a scorbutic state of
I. Serres found the portio major of the fifth nerve in a
te as far back as the pons Varolii, (*Magendie's Journ.*
here blindness was the consequence of the opacity of the
l the other affections of the senses, as well as the convul-
right side of the body, are accounted for by the diseased
brain. The inferences which have been drawn from this
oreover shown to be completely groundless by another
ase of the whole trunk of the fifth, in which there was
of the entire left side of the head, of the nose, tongue,
while vision remained perfect. (*Müller's Archiv. für
Physiol.* 1834, p. 132.)

CHAPTER II.

OF THE PECULIAR PROPERTIES OF OTHER NERVES.

Of the Nerves of the Eye.

We are ignorant as to whether the third, fourth, and sixth nerves have sensibility, in addition to their motor power. Desmoulins asserts that, when they are stretched or pinched, no pain is produced; but it is difficult to determine this with regard to such small nerves, particularly after the violence that is necessarily done to the animal in laying them bare.

The third nerve supplies the levator palpebræ muscle, the superior, inferior, and internal recti, and the inferior oblique; and from its branch to the latter muscle the ciliary or lenticular ganglion derives its short root, while the long root of this ganglion is supplied by the nasal branch of the fifth nerve, and contains a filament from the cavernous plexus of the sympathetic.

The influence of the third nerve and that of the nasal nerve on the iris deserve a special consideration. Desmoulins relates that, according to the experiments of Fowler, Reinhold, and Nysten, the application of galvanism to the third nerve causes a contraction of the iris. The excellent inquiries of Mr. Mayo have shown that the motions of the iris are regulated by the third nerve through the medium of the short root of the ciliary ganglion, and that they are in no way influenced by the long root of this ganglion derived from the nasal branch of tbe fifth.

The following are the results of his experiments on thirty living pigeons, in which birds M. Muck has shown that the ganglion ciliare has two roots, one from the third, the other from the fifth nerve.

1. When the optic nerves are divided in the cranial cavity of a living pigeon, the pupils become fully dilated, and do not contract on the admission of intense light. Magendie also observed dilatation of the pupil, and immobility of the iris, as a consequence of division of the optic nerve in dogs and cats; while the pupil became contracted, and the iris immovable, when the same experiment was performed on rabbits and guinea-pigs.

2. When the third nerves are divided in the cranial cavity of a living pigeon, the same result ensues; in both these cases the surface of the eyeball retains its feeling.

3. When the fifth nerve has been divided on one side in the cranial cavity of a living pigeon, the iris on that side contracts as usual on the admission of light, but the surface of the eyeball appears to have lost its feeling (which it derived from the twigs of the ophthalmic branch of the fifth).

4. When the optic nerves are pinched in the cranial cavity of a living pigeon, or immediately after its decapitation, the pupils are

for an instant on each injury of the nerves. A pheno- ierved by Flourens also.

n the third nerves are irritated in the living or dead bird, lt ensues.

n the fifth nerve is similarly irritated in the dead bird, no f the pupil is observed.

n the optic nerves have been divided within the cranial pigeon immediately after its decapitation, if the portion ves attached to the eyes be pinched, no contraction of the es: if the portion adhering to the brain be pinched, a like of the pupil ensues, as if the optic nerves had not been

revious division of the fifth nerves in the preceding ex- roduces no difference in the result.

n the third nerves have been divided in the cranial cavity g or dead bird, no change in the pupil ensues on irritating or divided optic nerves. (*Mayo's Anat. and Physiol. ries*, 1823, pt. ii. p. 4.)

ese experiments we may with confidence conclude that the er of the ciliary ganglion and the ciliary nerve is derived ird nerve, and that the light does not cause the contrac- pupil by acting directly upon the ciliary nerves; but that n of the retina and optic nerve acts immediately upon the from the brain is reflected upon the third nerve and the r root of the ciliary ganglion.

e have voluntary power over the motions of the iris; in ls, whenever the third nerve is excited to action by voli- is contracts. Now, in looking at near objects, the axes of e made to converge,—the eyes are turned inwards; and n we direct our eyes to near objects, the pupil becomes racted, but dilates when we look at distant objects. The mes very narrow in birds when we approach them, and e agitated; but the motions of the iris are not really more he will in them than in man.

however, the branch of the third which goes to the in- s muscle only that has this sympathetic influence over the branches, more especially that which supplies the inferior scle, have the same power. The inferior oblique muscle eye so as to carry the pupil upwards and inwards: if this is executed voluntarily, the pupil becomes much con- he eye takes this position involuntarily when sleep is in sleep itself, in the state of intoxication, and in hysterical nce we find the pupil contracted during sleep.

tracted pupil of sleep can, however, be made to contract according to the observation of Mr. Hawkins, (*Mayo's ries*, pt. ii. p. 6,) by the admission of intense light. At the waking, the pupil, after a few irregular contractions, as- sual degree of dilatation.

d nerve seems to determine only that movement of the produces contraction of the pupil. There are many circumstances, however, which render it probable that the dilatation also of the pupil is an active state, and Valentin (*De functionibus Nervorum*, p. 107–113,) labours to prove that it is a muscular movement, regulated by motor fibres of the superior cervical nerves.

The influence of the third nerve, as well as of the vagus and sympathetic, over the movements of the iris, is occasionally rendered manifest by disease in the human subject. A case in the *Medical Gazette*, for Sept. 1838, p. 16, referred to by Dr. Reid, and another, observed by Andral (*Clinigen Med.* tom. v. p. 135,) and quoted by Valentin, illustrates the action of the latter nerves on the iris. The association of paralysis of the third nerve, with the absence of power in the iris to contract the pupil, was well exemplified in a man recently under the care of Dr. Latham and Dr. Burrows at St. Bartholomew's Hospital. In this case complete, or nearly complete, paralysis of the levator palpebræ, of the obliquus inferior, and of all the recti muscles, with the exception of the rectus externus, was accompanied by a slightly dilated and perfectly fixed state of the pupil of the same eye. The strongest light did not cause the pupil to contract, although the retina and optic nerve seemed to be sound. The slight impairment of vision which was observed, was apparently dependent on the eye having lost its power of adaptation to distances; for whilst the patient could not distinguish well small and near objects, his perception of larger objects, at the distance of a few feet, was as perfect with the paralysed as with the sound eye. And since the changes in the eye by which it adapts itself to the vision of near objects are evidently connected by association with the action of muscles supplied by the third nerve, and with the act of contraction of the pupil, the loss of the power of adaptation in the above case was a circumstance of interest. It was remarkable that the application of belladonna to the eyebrow caused greatly increased dilatation of the pupil.

The facts drawn from *comparative anatomy* are generally confirmatory of the foregoing physiological results. The ciliary nerves are constantly supplied from the third nerve and nasal branch of the fifth.

The fifth nerve.

In the section on the sensitive and motor nerves, we have spoken of the sensitive and motor portions of this nerve, and have shown that its first and second divisions are, in the human subject, sensitive only; that the branches of the third division, which is composed of both motor and sensitive portions, are in part motor, in part sensitive. This important nerve, to which the anterior and lateral parts of the head, and the cephalic tracts of the mucous membranes (the mucous membranes of the mouth and nose, and the conjunctiva) owe their sensibility, and the muscles of mastication their motor power, communicates by each of its principal divisions with the sympathetic nerve; and its branches probably receive, through the medium of these communications, organic fibres from the sympathetic.

he facial nerve, or portio dura of the seventh.

h the facial nerve contains a certain proportion of sensi-
yet it is the principal motor nerve of the face: its sphere
xtends to all the muscles of the face, those of the ear, and
-frontalis muscle; besides several other muscles, namely,
or belly of the digastricus, the stylo-hyoideus, and the
muscle of the neck. Hence it is the nerve of expression,
e respiratory muscle of the face, since it is sympathetically
all violent or laboured respiratory movements.
ure of the connection of the facial and lingual branch
h nerve in man and Mammalia *by means of the chorda*
s not all understood.

The glosso-pharyngeal nerve.

e already considered the properties of this nerve with re-
motion and common sensation. It supplies the posterior
dorsum of the tongue, the papillæ vallatæ, the tonsils, and
x. Whether it also supplies fibres for the sense of taste,
er of doubt. The circumstance that the gustatory nerve
d some Amphibia is a branch of the glosso-pharyngeal,
r of such being the case. In the frog, the gustatory nerve
of the vagus. We do not know, indeed, how far the
ste extends. The sensations of disgust or nausea, which
principal seat in the pharynx, are, in a great measure,
he sensations of taste; and, with regard to these sensations
it is doubtful whether they are seated in the pharyngeal
the vagus, or in the glosso pharyngeal nerve. See page
observations of Valentin and Wagner, tending to prove
sso-pharyngeal is the true nerve of taste, are mentioned.
panic branch of the glosso-pharyngeal nerve ought pro-
regarded as a filament sent from the sympathetic to this

Nervus vagus.

xed nerve, which acquires its motor influence in a great
robably by its connection with the inner portion of the
ssory, is constant in its distribution to the organs of voice
tion, and to the pharynx, œsophagus, and stomach.
agus depend the sensations of hunger and satiety, and all
feelings which accompany respiration in health and dis-
et* has observed, that the sensation of hunger was no
after the vagus was divided. In a monster, of which the
horax were double, and the abdomen single, drink given
half did not satisfy the thirst of the other, probably on
the stomach being double.
us nerve contains many organic fibres derived from the
c, which attach themselves in part to the trunk of the

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hes sur les Fonctions du Syst. Ganglionaire, p. 179. Paris, 1830.

vagus, and in part to its branches. To these superadded organic fibres the vagus probably owes its organic chemical influence.

The chemical process of respiration, and the secretion of mucus in the lungs, are probably in part dependent on the influence of this nerve; at all events, the division of the vagus in the neck is followed by the effusion of bloody fluid in the lungs; and, although the chemical process of respiration is at first not essentially disturbed, yet the animals die a few days after the operation,—birds live at most but five or eight days. [With reference to the cause of death after division of the vagi nerves, see page 327.]

The secretion of the gastric juice also is subject to the organic influence of the vagus. The division of the vagus in the neck does not completely arrest the secretion of the gastric juice, but causes it to go on less actively; the effect on digestion is the same; in birds, which live longer than Mammalia after the operation, digestion is distinctly performed, but much more slowly than before. The circumstance of the chemical processes in the lungs and stomach not being immediately quite arrested, is sufficiently explained by the anatomical fact, that the vagus receives organic fibres, not merely at the upper part of its trunk, but at its lower part also, having there numerous connections with the sympathetic nerve, the influence of which cannot be cut off by the division of the vagus in the neck. The secretion of mucus in the respiratory organs appears to be in all parts under the influence of the organic fibres superadded to the vagus; and therefore it is, probably, that the recurrent nerve, at the point where it makes its turn, receives so many large communicating filaments from the sympathetic.

The division of the vagus on both sides does not arrest the absorption of fluids, or of foreign matters mixed with them, such as poisons, &c. from the stomach. The division of the vagus on both sides is fatal in very few days; but the division of one vagus nerve only is not fatal, nor indeed of both, if sufficient time have elapsed before the division of the second for the first to have become entirely reunited.

Nervus accessorius Willisii.

The relation of this nerve to the vagus, in respect of the motor power of the latter, we have already discussed. The sphere of action of the spinal accessory in Mammalia,—of that part of it, namely, which does not unite with the vagus,—includes the sterno-mastoid and trapezius muscles. The cause of the singular origin and course of this nerve is not well known. Perhaps it is that the pharyngeal branch given off from the vagus immediately after its exit from the skull, may receive fibres from nearly the entire cervical portion of the spinal cord. There are other nerves also which have an origin of great extent; for example, the ramus descendens noni arises from the hypoglossal nerve, and from the upper cervical nerves. The only difference between such cases and that of the spinal accessory is, that the latter nerve is formed within the spinal column, while other nerves do not receive the ıres composing them until after their escape from the

The hypoglossal or ninth nerve.

ion of this nerve in the cerebro-spinal system has been ırmined. It is essentially motor, but has likewise some ıres. In some Mammalia, according to Mayer's dis- ıs a delicate posterior root with a ganglion. It is the of the tongue, and of the large muscles of the neck, the larynx.

ıus reviewed the varieties in the origin and distribution ral nerves in different classes of animals, we will now far it is possible to reduce them to a fundamental type. ıich must guide us here is that first announced by Meckel, on of these nerves into *primitive and derivative.* The e the three nerves of special sense,—the olfactory, optic, , and the mixed or double-rooted cerebral nerves, which after the type of the spinal nerves, and which may be cephalo-vertebral nerves. The *derivative nerves* are produced by the separation of a part of the fibres from the *imitive* cerebral nerve, or as may become entirely united stance of other, cephalo-vertebral, nerves. Meckel has ied out this idea, which, as a general principle, is correct. made a better application of it. He admits the existence bral nerves of the head, of which the first is the fifth, with f the muscles of the orbit and the facial nerve, which he elonging to the motor portion of the fifth. The second rve of the head is formed, according to Arnold, by the l accessory, glosso-pharyngeal, and hypoglossal.* Ac- ny view, there are three vertebral nerves of the head, are three cranial vertebræ. The first is the fifth nerve; the vagus, with the glosso-pharyngeal and accessory the third, the hypoglossal. The nerves of the orbital third, fourth, and sixth, are derivative nerves, and are ed as the motor portion of the first division of the fifth. ea, the first division of the fifth gives branches to the ıe orbit, the ordinary nerves of these muscles being also the frog, the sixth nerve becomes united with the Gas- ion: here, therefore, the fifth gives branches to the orbital the Petromyzon, one of the three muscular nerves of obably the sixth—is wanting; and here, also, the fifth ıes to the muscles of the orbit. The facial nerve is cer- vative nerve, and resembles very much a motor portion for, in the osseous fishes, it unites into one cord with this ıs Serres supposed, forms its opercular branch. In the associates itself to the fifth. But the facial has an equally n to the vagus; in man and Mammalia it is connected

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ıuechner, Mém. de la Soc. d'Hist. Nat. de Strasb.; and Müller's p. lxxiv.

with branches both of the fifth and of the vagus. In serpents and lizards it gives a communicating branch to the vagus. In the frog, also, after being connected with the fifth, it becomes united with a branch of the vagus,—the jugular branch. The facial nerve in the lamprey (Petromyzon) forms, together with the vagus, the nervus lateralis, which in osseous fishes is frequently formed by the fifth and the vagus.

The second vetebral nerve of the head comprehends the vagus, glosso-pharyngeus, and nervus accessorius. The vagus is in greater part, but not wholly, sensitive [see page 521, et seq.]; the spinal accessory, in greater part, but not wholly, motor; the glosso-pharyngeal nerve, equally sensitive and motor. [? See page 521.]

The third vertebral nerve of the cranium is formed by the hypoglossal nerve alone. In the myxinoid fishes there is the nearest approach to the simple type of the vertebral nerves. The facial is in them the only *derivative nerve.*

SECTION V.

OF THE CENTRAL ORGANS OF THE NERVOUS SYSTEM.

CHAPTER I.

The central organs of the nervous system considered generally.

Functions of the central organs of the nervous system.—The activity of all the functions of the nerves is determined by the central organs, partly under the influence of the mind, and partly independently of this influence. The central organs form the connecting medium between all the nerves, or conductors of nervous influence. They act as excitors, or motors of nervous action, in determining the motor nerves to the production of contraction in muscles; and in this their action may be automatic, or voluntary, as the consequence of incitements of the sensorium commune seated in them; when automatic, their action may be either constant or intermittent. Moreover, the central organs have the power either of reflecting the centripetal actions of sensitive nerves upon motor nerves, or of communicating them to the sensorium commune, the seat of consciousness. By the central organs, too, the organic actions of the nerves are maintained in unimpaired power; by them the nervous principle is constantly generated and regenerated; and without them the power and excitability of the nerves as conductors of nervous action cannot be long preserved. This is the general definition of the relation in which the brain and spinal cord stand to the nerves. The correctness of this definition is readily proved by reference to facts already detailed.

1. *The central organs connect all the nerves into one system.*—To this even the sympathetic nerves do not form an exception; for,

shown in the preceding section, they are connected at
points with the central organs by fibres passing from the
ther. The only difference between the cerebro-spinal
the organic nerves, in their relation to the central organs,
former issue much more directly from them; while the
ves, although their fibres are in company with the cere-
nerves brought into communication with the brain and
, nevertheless have subordinate central organs in their
l plexuses, from which the organic nervous influence
diately emanates; still, however, the action of this organic
ot be long maintained when cut off from its communica-
e brain and spinal cord.

ntral organs are the excitors of the motor nerves which
motor influence of the nervous principle to the mus-
motor influence may be constant, as we see in the case
cters, the action of which is put an end to by injuries of
organs; secondly, it may be evidenced in intermittent
ovements, such as those of respiration, which are de-
the medulla oblongata; and, thirdly, this motor influ-
sue voluntarily from the sensorium commune of the cen-
this sensorium commune being subject to the spontaneous
e mind.

r nerves are affected by this motor influence in two
erves of one class act as mere conductors of it. They
it is true, charged as it were with motive power, and can
exert a motor action by being merely mechanically irri-
the normal state they do not exert this power sponta-
only when excited by the central organs; these are the
s of the cerebro-spinal system. The nerves of the other
are quite withdrawn from the influence of the senso-
une, as far as regards voluntary actions, are likewise
eing excited to constant or periodical action by the cen-
but they present the peculiarity of affording independent
f nervous influence, although, after a time, communi-
the central organs is found to be necessary for the repro-
heir nervous power: such are the sympathetic nerves
to their motor actions. The parts which are subject to
etic nerve, as the heart and intestinal canal, continue to
ntaneously, even when all communication with the cen-
s cut off; but the force and duration of their contractions
pendent on the communication of these nerves with the
inal cord. During temporary fatigue, as well as during
ensues after the daily action of the nervous system,
e of the central organs on the peripheral parts of the
vered; but this transitory altered state of the brain and
is not adequate to induce an essential change in the
parts subject to the sympathetic system. It is only
ate of exhaustion of the central organs becomes more
hen their integrity is essentially impaired, that the mo-
ed by the sympathetic nerves become paralysed.

It must not be imagined that during the state of fatigue of the central organs which returns every twenty-four hours, and during sleep, the brain and spinal cord become wholly inactive. The state of fatigue is certainly general, but the sensorium commune, that part of the brain on which the mind acts, is alone reduced to a state of especial inaction; the voluntary movements only are wholly arrested during sleep. The action of all other parts of the brain and spinal cord is maintained as at other times. This is evident from the sphincters continuing to act, and from the persistence of the rhythmic movements of respiration, both of which sets of motions are dependent on true cerebro-spinal nerves. Certain muscles, therefore, although supplied by cerebro-spinal nerves, continue to act even during sleep; the sphincters are always closed, and the eye is always turned upwards and inwards, and the iris contracted, so that the pupil is narrow; the mouth, too, is usually closed during sleep. In short, we see that, even in sleep, the whole motor apparatus of the central organs, of the brain as well as of the spinal cord, is in an active state, and that merely the voluntary excitation of this apparatus is absent owing to inactivity of the sensorium commune. We must, therefore, suppose that during sleep the influence of the central organs upon the sympathetic nerve is interrupted, for otherwise the power of that nerve to maintain certain movements would immediately begin to fail, as is distinctly seen to be the case in apoplexy, in syncope arising from affection of the central organs, and in the experiment of artificially destroying the spinal cord.

3. *Impressions conveyed by the sensitive nerves to the central organs are either reflected by them upon the origin of the motor nerves, without giving rise to true sensations, or are conducted to the sensorium commune, the seat of consciousness.*—In the first case, the centripetal actions of the sensitive nerves merely excite the motor apparatus of the central organs, which has its seat principally in the spinal cord, but of which there are also ramifications in the brain; in the second case, the sensitive impressions are conducted to a particular part of the central organs without exciting reflex movements, and are taken cognisance of in the sensorium commune by the mind. Since the phenomena of reflection are not dependent on the sensorium commune, but on the motor apparatus of the central organs, and since this apparatus continues in activity during sleep, these motions take place then as well as in the waking state; as is proved by cough from irritation of the trachea, and many other phenomena which occur during sleep.

4. *The organic functions of the nerves are maintained in unimpaired force by the central organs of the nervous system.*—In this respect the same relation prevails between the sympathetic nerve and the central organs as with reference to the motions of parts subject to the sympathetic. The action of the organic nerves in regulating nutrition and secretion is, in a certain degree, independent. The nutrition of the embryo proceeds, even to the full period, though the spinal cord and brain be destroyed by disease (see page

sult also *Eschricht, Müller's Archiv.* 1834, p. 268.) In
indeed, monsters consisting merely of a part of the body,
or an extremity, for instance,—in which no heart even
ed, have, nevertheless, been nourished; the blood being
it by branches of the umbilical vessels, and propelled
by the heart of another perfect embryo. But, in the
tion often suffers, although not always, in parts para-
disease of the brain or spinal cord; the paralysed parts
rone to gangrene when injured; and in violent acute
the central organs, with a depressed state of their func-
ene frequently arises spontaneously in individual parts of
In the later stages of tabes dorsalis, the tissue of the
ts erectile power, and the generative faculty is lost.
ervous principle is generated and regenerated in the
ns.—This is proved by the experiments instituted by
Dr. Sticker, which show that the nerves of a limb when
nication with the central organs is cut off, although for
possess motor power, yet, if they do not become reunited
roximal portion, lose, after a few months, all their excita-
r property of exciting motions when irritated mechani-
galvanism; a result from which we must conclude that
communication of the nerves with the central organs is
r the maintenance of the nervous power of the former,
e central organs still retain their power, when their
re lost to them. The maintenance of the excitability in
loes not, however, depend solely on the continuance of
of the central organs upon them, but also upon their
. If a nerve remains for a considerable time in an inac-
t gradually loses its capability of action. There are
s in the human body over which most persons have no
g to their not having used them; when the eye is affected
ss, the optic nerve becomes atrophied from the retina to
Magendie has observed this atrophy of the nerve ensue
few months after the artificial destruction of vision.
ration of animal matter which is endowed with life into
ns and other parts dependent on these central organs, is
of all animals; but, more than this, the tendency to this
implanted in the matter of the germ from its origin; and
at when this tendency comes into operation, the whole
of the germ commences. We have shown at page 47
ity that all animals, even those apparently the most
nerves distinct from the parts the action of which is
n them; and wherever the nervous system is susceptible
l examination, we find it in its turn consist of certain
ant central parts and their conductors, the nerves. In
of the higher animals this insulation of parts commences
germinal membrane; the portion of the animal matter
lowed with the powers of the central organs collects in
the membrane, while the parts dependent on the influ-
central organs are formed around. But a similar sepa-

ration and aggregation of parts goes on in this peripheral portion of the new being, by which are formed the nerves, the conductors of the nervous principle, and the tissues to which they communicate the influence of the central organs.

The formation of the central organs is necessarily attended with the formation of the peripheral parts; and, at the same time that the nerves are formed in these parts, the tissues, which are vivified by their agency, necessarily assume their existence. As soon as this separation between central organs and peripheral parts takes place, the brain and spinal marrow are virtually present; neither exists before this. The formation of the separate regions of the central organs is likewise the result of progressive development and separation of parts. The separation of the peripheral portion of the embryo into nerves and dependent tissues follows the same law; as soon as the separation commences, the whole nerve is present, the peripheral extremity of the nerve not being first formed, and the rest of it progressively towards the central organs, but the whole of its extent simultaneously. The opposite view, which was adopted by Serres, (*Anat. Comp. du Cerveau,*) is not supported, at least, by any facts; the observations which have been adduced in its support, have not been found correct by Baer, whose researches on the development of the embryo have acquired a classical value.

In vertebrate animals, the spinal cord has not that great influence over spontaneous and voluntary motion which the non-cerebral ganglia of the nervous system in invertebrate animals possess. Even vertebrate animals, however, after decapitation, execute movements which evince a certain degree of harmony and adaptation. Birds flap their wings; and frogs, as Volkmann remarks, resume their sitting posture. I have not myself, however, observed such spontaneous movements of decapitated frogs, except when the head was separated close to the occiput. When the section was made lower down on the spinal cord, the motions of the frog did not indicate the slightest degree of volition. Though birds still flap their wings when their spinal cord is divided in the middle of the neck, such actions are only grouped muscular motions, which are dependent on the spinal cord, and are very different from voluntary movements.

We are in possession of no facts which prove that the spinal cord, when separated from the brain and medulla oblongata, can be the seat of true sensation. The reflected motions excited by irritation of the surface in decapitated frogs are no proof of this; whenever these reflected movements present any degree of adaptation to a purpose, it is certain that the spinal cord has been divided at its very commencement.

In all the higher and lower Vertebrata the mass of the spinal cord in general corresponds to the magnitude of the body which receives nervous influence from it; the spinal cord of a fish is proportionally as large as the spinal cord of the human subject, but the brain increases in size in the higher animals in a direct ratio with the development of their mental faculties. Although all animals, from the infusory animalcules upwards, are equally perfect in their organisation

o what is necessary to animal life, yet we must admit a
n their degree of perfection in relation to intellectual de-
and the organs of the mental faculties; a difference which
displayed in the structure of the brain itself.

foregoing considerations it is clear that a comparison of
with the central organs of the nervous system (taken to-
th reference to their size in different animals, is not calcu-
rd any physiological inferences. The size of the nerves
ith that of the central organs will, it is true, on the whole,
we descend the scale; but this increase is not great, unless
be compared with the brain alone. The spinal cord,
des being a means of communication between the brain
is a motor apparatus, adapted to the motor powers of the
ars in all animals to correspond by its mass (not by its
breadth, which vary greatly,) to these motor powers, and
s which arise from it. The weight of the spinal cord of
(Gadus lota), as compared with that of the body of the
rding to Carus, as 1 to 481; in the land salamander, the
is to the rest of the body as 1 to 190; in the pigeon, as 1
he rat, as 1 to 180; in the cat, as 1 to 161. It is true,
fishes, nerves, such as the fifth and vagus nerves, which
ctually exceed the spinal cord in diameter. In comparing
nd spinal cord in different animals, however, we must
hickness of the nerves, but not the thickness of the spinal
e thickness and length at the same time, or rather the
of the cord, which must be compared with the aggregate
e nerves issuing from it. Moreover, the size of the cere-
which arise from the prolongations of the spinal cord in
annot, with any good result, be compared with the size of
pinal cord behind the brain.

oing general remarks are intended as introductory to a
inquiry into the functions of the brain and spinal cord
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CHAPTER II.

OF THE SPINAL CORD.

The spinal cord is distinguished by its mere anatomical structure from the nerves; it is composed of the same delicate fibres as the brain; it contains in its interior grey substance, the tranverse section of which has the form of a cross, whose arms or cornua are prolonged on each side into the anterior and posterior columns. The two kinds of grey matter and the *substantia cinerea gelatinosa* of Rolando have been treated of at page 494. But the disposition of the white substance also is peculiar. Rachetti and Rolando have observed that the white substance is divided into lamellæ, which run from without inwards, and which can be seen in sections of the spinal cord that have been kept for a long time in common salt. Rolando moreover maintains that these are the numerous longitudinal parallel folds, into which the membrane-like expansion of the white substance is thrown, and between which thin processes of the pia mater pass from without inwards, while, from within, thin layers of grey substance are received between them. In the anterior white commissure between the two anterior columns of the cord, the white substance, or "medullary membrane," the folds of which form the white substance, passes across from one side to the other. This is not the case in the posterior furrow.

In a physiological point of view, the spinal cord so far agrees with the nerves that it propagates actions of the nerves, which enter it, to the brain, just as the cerebral nerves communicate impressions made on them immediately to the sensorium commune; and that it communicates the influence of the brain to the nerves arising from it, which thus receive, through the medium of it, the cerebral influence, just as if they arose from the brain itself; in other respects, however, the spinal cord differs essentially from the nerves in possessing properties which belong to it as part of the central organs, and do not reside in the nerves. We shall consider it more minutely, first, as a conductor, and then as a part of the central organs.

1. *The spinal cord as conductor of the nervous principle, or of its oscillations.*—All the cerebral nerves are immediately subject to the influence of the brain, and all the spinal nerves are subjected to the same influence, through the medium of the spinal cord. As soon as the transmission of this influence is interrupted, impressions on sensitive nerves cease to be propagated to the sensorium, and the brain loses the power of voluntarily exciting the motor action of the nerves which are withdrawn from its influence.

The causes which interrupt the communication of the brain and spinal cord with the nerves are pressure upon the nerves, destruction or division of them, and paralysis of their motor power by substances soluble in the fluids of the body, as in cases of poisoning by lead.

ese causes act on a nerve, all its branches which are given
he affected spot cease to be voluntarily excited to motor
the muscles which these branches supply are paralysed
l to voluntary motion; the action of external stimuli, too,
e parts produces no sensation.

ranches, on the contrary, which come off from the nerve
point of injury, are still subject to the influence of the
f volition, and when irritated give rise to sensation; the
bres which compose them being still in unimpaired con-
h the brain.

s of a nerve below the injured point preserve, however,
power for a certain time; it is merely the influence of the
them that is lost. Hence, when a nerve which is paralysed
ary motion, from being withdrawn from the influence of
r cut off from its connection with that organ, is pricked or
vhen heat, or a caustic substance, or electricity or gal-
applied to it,—no sensation is excited, it is true; but the
which the nerve sends branches are excited to contraction.
does not lose this excitability until it has been several
off from intercourse with the brain and spinal cord.

nd the higher animals the spinal cord stands in the same
ll the cerebral nerves to the brain; it is to be regarded
on trunk of the nerves of the body, although it is, besides
uished from them by special properties.

mpare with this statement the consequences of injuries
l cord. Lesion of the lowest portion of the spinal cord
lysis of the inferior extremities of the rectum and blad-
sion is situated at a higher point of the cord, the abdomi-
are paralysed in addition; if at a still higher point, the
scles also: lesion of the spinal cord in the cervical region,
he origin of the fourth cervical nerve, paralyses all the
mentioned, and the arms likewise, but not the diaphragm;
nic nerve arises from the fourth cervical nerve: injury to
oblongata paralyses the whole trunk. When the lesion
extends progressively from below upwards, the paralysis
extends in the same manner from the lower to the upper
observe in tabes dorsalis. Thus, in the paralytic effects
he spinal cord presents every resemblance to a common
nerves of the body. Moreover, if we irritate the upper
pinal cord mechanically, or by galvanism, all the muscles
are thrown into contraction, just as the muscles which
nches from a particular nerve are made to contract by
e stem of the nerve. Again, if we divide a nerve, the
off from communication with the brain still retains the
xciting, when irritated, contractions in the muscles to
listributed; and, in the same way, if we divide the spinal
nimal, the part withdrawn from the influence of the brain
rritated, still excite to action the nerves which arise from
cause the muscles to contract.

pinal cord does not merely represent in the brain all the nerves of the trunk in the aggregate, but also all the individual primitive fibres of these nerves singly; the affection of certain parts of the spinal cord interrupts the transmission of nervous influence to certain muscles of the trunk only, and lesion of certain parts of the brain paralyses only certain parts of the body. A cause of paralysis affecting only one side of the brain and spinal cord gives rise to paralysis of one side of the trunk only; and the less extensive the lesion,—the less it embraces of the columns of the spinal cord,—the smaller is the number of parts which are deprived of the influence of the brain. If, moreover, we consider that it is the action of the brain which regulates the number of muscles that are called into action in every voluntary motion, it will appear as a necessary inference that the primitive fibres in the spinal cord do not unite with each other, but continue their separate course as in the nerves, so as to communicate isolated sensations to the brain, and to transmit from the brain the stimulus for isolated motions; for, if the nervous fibres coalesced in the spinal cord, neither a local isolated sensation nor an isolated contraction of separate muscles would be possible. Irritation of certain parts of the brain and spinal cord gives rise also to muscular spasms, or to sensations in isolated parts of the trunk.

The primitive fibres, as they issue from the spinal cord, are not already arranged into separate nerves; but the nerves are formed by the radicle fibres being collected into fasciculi. The anterior and posterior roots of the nerves are, it is well known, inserted into the anterior and posterior columns, at a little distance on each side of the middle line. The fasciculi which form the roots of the nerves of the cauda equina are inserted close to each other in an uninterrupted series; the radicle fasciculi of the rest of the nerves pierce the pia mater at a little distance from each other. But, when they are traced still deeper, the fibres are found to spread out still more, and to form a tolerably continuous line of insertion, the root of each spinal nerve being formed by the union of a certain number of the radicle fasciculi. We may, therefore, regard the spinal cord as a trunk formed of nervous fibres, which sends out, anteriorly and posteriorly, in uninterrupted series, many millions of primitive fibres of motor and sensitive endowment to all parts of the body; these fibres being between their origin and their peripheral termination collected into numerous large and small fasciculi by means of cellular sheaths.

With respect to the relation which exists between the nerves and spinal cord, comparative anatomy affords us no information. The proportional length of the spinal cord varies very much.

The discovery that the anterior roots of the spinal nerves are motor, and the posterior sensitive, (see page 515,) has thrown great light on the different kinds of paralysis. We know that in some cases the sensibility of a limb, or of one whole side of the body, or of the lower half, is lost, the power of motion remaining unimpaired; that in other cases the sensibility is perfect, and the power of motion only lost; and again, that in a third order of cases the paralysed parts are deprived both of motion and sensation. Now we are naturally led to inquire whether the same difference as to motor and sensitive power, nguishes the roots of the nerves, prevails also in the spinal ie motor and sensitive fibres run separately in the spinal brain? The differences in the various cases of paralysis ɔw that such is the case; for the remarkable pathological ɜ mentioned cannot otherwise be explained. But it is tter to determine which are the motor, and which the sen- of the spinal cord. It may be supposed that the anterior ɔm which the motor roots arise are themselves motor, and or columns from which the sensitive roots arise merely ıroughout the whole length of the spinal cord; or it may ıed whether the white substance of the cord be not en- ı the one function, the grey substance with the other. In he first supposition, which is that adopted both by Sir C. 1. Magendie, no satisfactory proofs have been adduced experiment or disease. It is impossible to determine it ıent; for, in applying the knife to the posterior columns, nenter necessarily subjects the anterior columns to pres- anterior and posterior columns cannot indeed be shown to cally distinct.*

ems, unfortunately, to be no possibility of determining by the share which the white and grey substances of the espectively in the functions of motion and sensation, and iments on the anterior and posterior columns are rendered e by the circumstance of the spinal cord having the power upon its motor apparatus impressions primarily made on e or centripetal fibres. Even supposing, for example, terior columns were solely motor, and the posterior sensi- ury to the posterior columns would nevertheless be very cite muscular contractions by virtue of its secondary in- the anterior columns; all severe lesions of the cord throw- he peculiar state in which any irritation propagated to it ive nerve is reflected upon motor nerves. (See page 551.) ɜs of the spinal cord pass through the medulla oblongata e sensorium commune. All the primitive fibres of the ninate in the brain; those of the cerebral nerves imme- se of the spinal nerves through the medium of the spinal brain (we do not here inquire into the properties of its ırts) receives the impressions of all the sensitive fibres of ecomes conscious of them, and recognises the seat of the according as different primitive fibres are affected; the on the other hand, excites the motor power of all the s, and of the spinal cord, giving rise thus to the voluntary n this action of the brain we can but admire the infinitely l and delicate mechanism, though the powers by which it holly unknown to us. And different as the two organs r respects, we cannot avoid recognising in the action of when it calls into activity a certain number among the

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his as my opinion in my memoir on the roots of the nerves in the :ieno. Nat. 1831.

infinitely numerous primitive nervous fibres, a similarity to the play of a many-stringed instrument, the strings of which vibrate when the keys are touched. The mind is the performer or excitor; the primitive fibres of all the nerves which spread out in the brain are the strings; and their cerebral extremities, the keys. Niemeyer supposes voluntary motions to result from the tension of the antagonistic muscles being arrested.

The spinal cord resembles the nerves again in the sensations produced by any affection of it being referred to the extreme parts. Pressure on a nerve gives rise to the sensation of creeping in the skin; pressure also on the spinal cord causes the same sensation to be felt in all the parts which receive their nerves from it below the seat of the lesion. Division of nerves, or tumours of them, cause severe pain to be felt in all the parts to which the nerve is distributed; in the same way inflammatory and other affections of the spinal cord are often attended with severe pains in the extreme parts of the body. Even when there is perfect insensibility to external stimuli, lesions of the spinal cord may still excite sensations which are referred to the peripheral parts. Thus, in cases where the lower extremities are completely deprived of motion and sensibility, the sensation of creeping may still be felt in them. (See *Ollivier, De la Moëlle Epinière, et de ses maladies*. Paris, 1823.) The sensations in these paralysed parts may indeed amount to severe pain, as in the axiom already mentioned (page 539). The sensation of creeping of ants over the surface is, however, the most frequent symptom in affections of the spinal cord, and is indeed scarcely ever absent. It is analogous to the tinnitus aurium seated in the auditory nerve, and to the muscæ volitantes and other morbid phenomena of vision; and, since the motion of the blood in the retina of the healthy subject gives rise to the appearance of points flying about whichever way the eye is directed, this feeling of creeping of insects or of the running of points over the surface is probably the effect of the motion of the blood in the capillary vessels of the diseased part of the spinal cord. In some instances, in place of the creeping sensation, there has been an incessant itching of the legs, which could not be removed by scratching. (Ibid.) The aura epileptica is another similar symptom of affection of the spinal cord.

Since the true seat of sensation is not in the nerves, nor in the spinal cord, the necessary currents or oscillations of the nervous principle being merely transmitted by them to the sensorium commune, where the sensation is really perceived, it is easy to conceive why the same sensation should arise from irritation of the fibres of the spinal cord, or of the nerves, at very different points of their length; for each nervous fibre, however long, can act on the sensorium by its cerebral extremity only, at however many different points of its length it may be irritated. The same apparent contradiction, however, is met with here in the case of the spinal cord as in that of the nerves, namely, that pain is not merely felt in all the parts which receive nerves from below the seat of the lesion, but that the injured or diseased part itself is painful. There are many cases of pain pine which are not instances of this; diseases of the spinal elf, namely, and of the membranes of the cord, are necesided with pain, while they may by producing pressure on cord give rise to the usual symptoms in the extremities. re instances of pain really affecting the spinal cord itself,—

The sensations of rigour and cold trickling down the also be seated in the spinal cord. We are at present ignoensations should at one time be felt in the peripheral parts, her in the spinal cord itself.

hitherto considered merely the points of similarity benerves and the cord, regarding the latter as a conductor of nerves to and from the brain; we will now inquire into erties of the spinal cord which distinguish it from the which it enjoys as a part of the central organs.

pinal cord, as a part of the central organs of the ner-n.—The anatomy of the spinal cord is alone sufficient to t is not merely a conductor of the nerves to the brain; if h, it would, like any other nervous trunk, consist at its merely of the aggregate of the nerves which it gives off ent points of its length, and it would diminish gradually above downwards in proportion as the nerves leave it, regularly tapering and pointed cone. But although, on it does not become smaller from above downwards, yet, nity, where it gives off the last nerves, it is of greater would be formed by the fibres of those nerves: moreover, enlargements opposite the origin of the nerves of the and in fishes it forms at its lower end a club-shaped enpointed below. Further, the spinal cord is formed, like f two distinct substances.

roperties and functions also which distinguish the spinal ne nerves can be distinctly indicated.

pinal cord has the property of reflecting sensorial irritasensitive nerves upon the motor nerves. This property, of which a sensitive impression gives rise to motions, ere is no communication between the primitive fibres of ds of nerves, has been treated of in the Chapter on Reions.

pinal cord has the property of reflecting the action of rves upon motor nerves, without itself perceiving the We have already shown, in the chapter on reflected , that the action of the sensitive nerve is most prone to on the motor nerves which arise near the same part of ord; and we cannot be surprised, therefore, that irritation of the foot excites retraction of the foot; irritation of the arm, retraction of the arm. An equally involuntary e irritated parts is excited in our own persons by a severe by irritation of the mucous membrane of the pharynx, trachea. The retraction of the extremities in a decapiwhen the skin is irritated, is, therefore, quite as independiousness and volition, as the general tetanic spasm excited by touching the skin in a decapitated salamander or in a frog poisoned with a narcotic substance. Moreover, reflected motions are excited during life in the human body, quite independently of consciousness. In the movements of the muscles of the trunk which attend vomiting, and which are excited by a morbid state of the stomach, intestine, kidney, liver, or uterus, the irritation in these different organs is very frequently, and generally indeed, not felt; that is to say, the centripetal excitement of the sensitive nerves, which is propagated to the spinal cord and medulla oblongata, does not act on the sensorium commune. And thus we see distinctly that the reflex action of the spinal cord is not necessarily attended with sensation or perception of the sensitive impressions, and that the arguments adduced from the reflected actions for the existence of consciousness in the spinal cord are unfounded. The head, also, when separated from the trunk, may exhibit the phenomena of reflected motion, although it is not in the slightest degree probable that the head of a man, or one of the higher animals, is, when separated from the trunk, capable of conscious perception.* The loss of blood accompanying decapitation, independent of the other effects,—such as the division of the upper part of the medulla,—is greater than any which usually deprives the human subject of consciousness. The contraction of the muscles of the face, when the stump of the spinal cord in the head of a decapitated criminal is irritated, is no more than must necessarily occur.

c. The spinal cord is a motor apparatus which, even when separated from the brain, and without any external stimulus, can excite automatic movements. The nerves, at all events those of the cerebro-spinal system, have not this power, although the motor action of the sympathetic system in this respect resembles that of the spinal cord.

d. The spinal cord, although capable of exciting the motor nerves to automatic actions, nevertheless, in the healthy state, leaves a great part of the motor nerves, those supplying the muscles of locomotion more especially, in a quiescent state; while on many others it exerts a constant motor influence; maintaining thus constant involuntary contractions, which are arrested only by the spinal cord becoming paralysed.

e. The spinal cord has a great tendency to propagate a particular state of one part of itself to other parts; in this property it differs entirely from the nerves. A nerve does not so readily communicate a change in its state, such as is produced by galvanism, to the whole spinal cord, provided the cord itself be not irritated.

f. The spinal cord, when in a state of great irritation, whether this arises from inflammation, from violent irritation of nerves (as in traumatic tetanus), or from the action of narcotic poisons, emits a constant motor excitement to all the voluntary muscles.

g. When animals are poisoned with narcotic substances which

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* See the account of Bischoff's experiments on a decapitated criminal in Müller's Archiv. 1838, p. 496.

) convulsions, the spinal cord, and not the nerves, is the
ıe motor influence that excites the movements. If the
n extremity be divided before the nux vomica or strych-
oduced into the system, no cramps are produced in that
efore or after the animal is poisoned, the spinal cord be
the cramps nevertheless take place in the parts supplied
r half of the cord.

orce of our voluntary movements is also dependent on ?
ension of the spinal cord. The intensity of our muscular
a great measure dependent on it. The greater part of
erves are, it is true, excited to action, not by the spinal
nly by the influence of the will, and when this is not in
ey are left in a quiescent state; but nevertheless the force
n of the motor actions excited in these nerves by the sen-
mune are determined by the spinal cord.

inal cord is the source of the sexual power; the exercise
l function depends on it. The spinal cord is incontesta-
of the nervous system most affected in the act of coitus;
nt from the energetic reflected motions excited by the
the sensitive nerves of the penis, the contractions of the
ninales and perinæal muscles. The state of exhausted
ower which follows the act must have its source in the
The degree of tension of the nervous power of the cord
cessary for the sexual appetite is only gradually regained,
sues that state in which erection of the penis is excited
that the mind is directed to objects relating to the sexes;
on on the sensorium causing such a discharge, as it were,
ummulated in the spinal cord as gives rise by the organic
luence to the accumulation of blood in the penis. The
ncy is also lost in diseases of the spinal cord.

ıfluence exerted by this organ upon the organic chemical
the capillaries, through the medium of the organic nerves,
ot only by the altered state of the cutaneous secretion in
t still more clearly by the condition of the skin in men in
pinal cord has become affected in consequence of sexual
these cases there is not merely general loss of power, but
shed turgescence of the skin, diminished perspiration,
he skin, and defective generation of heat; the feet, hands,
are cold.

inal cord is also the subject of a morbid impression in all
tions; and the peculiar alteration of the sensations and
d of the organic processes, the secretions and generation
fever can only be accounted for by the influence of such
that which we have been considering in this chapter.
ions of the cerebro-spinal nerves do not usually give rise
t rather to other affections of the nervous system, and
s most frequently excited by altered action of the capillary
me part of the body,—whether such as attends affections
ous membranes, or inflammation of some organ,—it is
probable that such an impression as would be produced

by severe lesion of the organic nerves in any part of the body (whether from inflammation or other cause of irritation), is in fever propagated to the spinal cord, and thence reflected upon all the nerves of the body.

With regard to the organic actions of the spinal cord as compared with the brain, it has been shown by the experiments of Flourens, which Hertwig* has confirmed, that a bird will continue to be nourished for a considerable time—will not become emaciated, after the cerebral hemispheres have been removed, if food be forced into its mouth.

CHAPTER III.

OF THE BRAIN.

I. *Comparative anatomy of the brain of vertebrate animals.*

In no part of physiology can we derive greater aid from comparative anatomy than in the physiology of the brain. Corresponding with the development of the intellectual faculties in the different clases, we meet with very great differences in the form of the brain, which are highly important in aiding us to determine the functions of the different parts of the organ. A knowledge of the comparative anatomy of the brain is also indispensable in the performance of experiments on animals, with a view to ascertain the properties of its individual parts. I have on these accounts thought it necessary to preface the inquiry into the physiology of the organ by a review of its different forms in the vertebrate classes.

A superficial comparison of the brain of the human subject with that of the higher animals is sufficient to enable us to recognise one important difference: it is, that the cerebral hemispheres, which in man overlap posteriorly not merely the corpora quadrigemina, but even the cerebellum, diminish more and more in their extent in that direction as we descend the scale, so as to leave those parts uncovered. In Rodentia the cerebellum is already half exposed; in birds the corpora quadrigemina have come to view; and they are more completely bare in reptiles. In proportion as the cerebral hemispheres diminish in size, the corpora quadrigemina or optic lobes enlarge; and although in reptiles they are still considerably smaller than the cerebral lobes, in fishes the relative size of the parts is so altered that it is difficult to determine what each represents. The brain of fishes consists merely of a series of double and single enlargements. The most posterior is single, and lies upon the medulla oblongata, covering the fourth ventricle; it is the cerebellum. In front of this are two bodies, frequently the largest of all, and hollow ior; the optic nerves arise in greater part from them. More e two solid bodies connected together in the middle line; ly in front of these, at the origin of the olfactory nerves, are largements not united together.

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* Experimenta quædam de effectibus lesionum in partibus Encephali. Berol. 1826.

brain of the higher vertebrata, and that only, resembles in re the brain of the lower vertebrate animals; for in it the are small, and do not overlap either the cerebellum or the drigemina, and at a very early period the latter bodies are than the cerebral lobes. At this time the brain of the als presents a series of enlargements, like that of fishes. lum forms a single lobe, posteriorly, in the middle line; in e the large vesicular corpora quadrigemina, not yet divided rior and a posterior pair of elevations, the cavity in their ng the ventriculus Sylvii, which afterwards is reduced to tus Sylvii; and, lastly, we meet with the cerebral hemis- the olfactory lobes at their anterior extremity in Mam-

owers of the Brain, and the Mental Faculties, generally.

undergoes a gradual increase of size from fishes up to man, o the development of the intellectual faculties. Its pro- he mass of the whole body is stated by Carus (*Anat.* . l.) to be,—

In the Burbot (Gadus lota) .	as	1	to	270
Pike . . .	"	1	"	1305
Silurus . . .	"	1	"	1837
Salamander . .	"	1	"	380
Tortoise . . .	"	1	"	2240
Pigeon . .	"	1	"	91
Eagle . . .	"	1	"	160
Siskin (Fringilla spinus)	"	1	"	231
Rat . . .	"	1	"	82
Sheep . . .	"	1	"	351
Elephant . . .	"	1	"	500
Gibbon . .	"	1	"	48
Simia Capucina . .	"	1	"	25

mum weight of a horse's brain is, according to Soemmering, he minimum of an adult human brain, 2 lb. 5½ oz.; and the nerves at the base of the brain are ten times thicker than in the human subject. The brain of a whale 75 h, which is in the Museum at Berlin, weighed 5 lb. 5 oz. veight of the human brain is, according to Soemmering, ½ oz. to 3 lb. 1 oz. 7 dr. When now we recollect that the diminishes from Mammalia downwards in a far less inference appears manifest, that the development of the aculties in the animal scale is dependent, not on the size lla spinalis, but on that of the brain. The considerable its proportional size in one and the same class show also of the brain, as a whole, is not regulated by the mass of er which it presides, but that the motor apparatus propor- mass of the muscles of the body is to be sought in the spinal arts of the encephalon, however, do not keep pace equally with the development of the intellectual powers. It is in the cerebral hemispheres that the increase of size in the higher animals chiefly takes place. The cerebellum, also, becomes proportionally larger in animals higher in the scale, but in a far less marked degree. The corpora quadrigemina are actually smaller in proportion to the rest of the body; and the medulla oblongata, and its prolongations in the brain, are not proportionally larger in man than in any other animal. The nervous fibres from the whole trunk must in all animals equally pass through the medulla oblongata to reach the brain. Hence we perceive that the encephalon necessarily contains parts which have, in all animals, the same functions and vital importance; thus injury of the medulla oblongata is equally fatal to all; while injury to the cerebral hemispheres gives rise to a much slighter disturbance of the vital functions in reptiles than in animals endowed with higher mental powers.

We will not, however, at present enter into a consideration of the functions of the individual parts of the brain, independently of the intellectual faculties; but will first inquire into the relation which exists between the mind and the brain generally. Comparative anatomy alone suffices to show us that the source of the mental faculties must be sought in the brain; and experiments on animals, as well as the history of lesions of the brain in comparison with those of other organs, confirm this suggestion. We have now, in the first place, to prove that the mental functions are performed in no other parts of the nervous system, or of the body generally, but in the brain alone.

With regard to the nerves, we learn, from the effects of lesions, that, when cut off from communication with the brain, they are withdrawn from the influence of the will, and impressions on them are no longer perceived; and in this respect the spinal cord resembles them. On the other hand, the upper portion of a divided nerve, and the part of the spinal cord above the seat of the lesion, are still subject to the influence of the will, and the mind is rendered conscious of impressions made upon them. Thus, the organ of the mind loses none of its powers by this division of the nerves and spinal cord; merely the number of the parts to which its influence extends is diminished, just as by the amputation of his limbs a man loses none of his intellectual faculties.

Still less than the spinal cord can any other part of the body be the seat of the mental faculties. Limbs may be amputated, or viscera affected with gangrene, and the mind still may be clear, as long as life continues.

The effects of lesions of the brain are very different; every cause which disturbs its action slowly or suddenly affects at the same time the mind. Inflammation of the brain is never unattended with delirium, and at a later period with stupor; pressure on the cerebrum, whether produced by depressed bone, foreign bodies, serum, blood, or pus, always gives rise to delirium or stupor, according as there is or is not irritation with the pressure. The same causes, according to the seat of their action, frequently abolish the power of voluntary motion, or memory: and when the pressure is removed, the memory frequently returns; and it has been observed that the chain of thought was immediately resumed at the point where it was interrupted by the injury.

cerebral hemispheres in animals gives rise to stupor and
ry; and in most lunatics considerable structural changes
ace in the brain, although in other cases, particularly when
i inherited, the changes that have affected the microscopic
re cannot be recognised with our imperfect means of in-
id defective knowledge. It has been said, as an objection
eing regarded as the seat of the mind, that very consider-
as been found affecting an entire hemisphere without the
es having suffered: experiments on animals show, how-
n sudden lesion of one hemisphere only does not imme-
e complete stupor; that this effect does not follow until
ved; so that it would appear as if one hemisphere could
and even compensate for its inaction in the operations of
any distinguished writers, for example Bichat and Nasse,
admit that the brain is the seat of the higher intellectual
maintain that other organs also, as the abdominal and
a, have a certain connection with the mental functions,
the belief that the source of the passions may possibly be
s. They formed their opinion partly on the circumstance
of the chest and abdomen being affected during the preva-
ns of the mind, and partly on their being frequently dis-
of insanity. The intestinal canal, liver, spleen, lungs, and
inly frequently the seat of disease in lunatics, and occa-
when no palpable change can be detected in the brain
e the diseases of the abdominal or thoracic viscera may
exciting cause of the mental affection, but only in the
other causes might excite it by the impression communi-
rain; there being in it some pre-existing disposition to
either hereditary or acquired. Hence in these patients,
he morbid change in the other viscera which have in-
ain, the disposition in the latter organ to abnormal action
d again to a latent state.

in which the viscera stand to the mental emotions is, it
sed, still involved in much obscurity.(*a*) The passions,
e change which takes place in the brain, affect the whole
1. The exciting passions give rise to spasmodic actions
cles, particularly those of which the nerves belong to the
tem (including the facial nerve); hence the crying, sigh-
c. with the spasmodic distortion of the features. In the
sions, as apprehension and terror, all the muscles of the
tone, the supply of motor influence from the brain and
ng arrested; the feet are not able to bear the body, the
notionless and without expression, and the loss of power
at as to cause momentary paralysis of the whole body,
the sphincters. The motions of the heart are affected by
ing and depressing passions. The sensations of many
ed. The secretions, as those of the lachrymal gland and

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owledge and much suggestive matter on this subject will be found
Physiology. (See Translation, 3d edit.—By Drs. Bell and La

skin, are affected; the bile is not properly excreted, and permeates the coats of the blood-vessels so as to produce jaundice; the urine, lastly, becomes watery. The action of the capillaries is modified; hence the skin becomes red, or, in other cases, pallid. In short, the passions influence first the nerves engaged in the respiratory function; then, through the medium of the spinal cord, all the nerves of the trunk and extremities, as well those of animal life as the organic nerves. But I am not acquainted with a single fact which proves that, in a healthy person, a particular passion affects one organ more than another. It is usual to say that the heart is affected by joy, sorrow, and anxiety; but does not every exciting or depressing emotion alter its action? Does not the heart stand in the same relation to the mental emotions as the lachrymal organs, which are affected by every emotion of the mind when it reaches a certain intensity? It is an old notion that the liver has a special relation to the passions of rage and vexation. Jaundice, with pain in the right side, or even inflammation of the liver, has certainly followed a paroxysm of these passions; but only in persons already suffering from affection of the liver, or having disposition to hepatic disease. Other persons, on the contrary, as a consequence of such emotions, have disturbance of the functions of the stomach; others again, an affection of the heart merely, this being in them the organ of which the action is most easily disturbed; and so it is with all the passions of the mind. In short, it is evident that the effects of the passions upon the different organs subject to the influence of the brain, in no way confirm the hypothesis of the passions or certain mental faculties having their seat in any other organ than the brain.

Although, however, we are satisfied, upon grounds derived partly from comparative anatomy, and partly from physiology and pathology, that the seat of the mental operations is the brain and no other part,—that the nerves excite those operations and are the instruments for executing what the mind directs,—and that all the other parts of the body are subject to the influence of the nerves, still this amounts to nothing more than that the brain by its organisation is the instrument by which the mind operates and is active: we do not assert that the "mental principle" has its seat in the brain alone. It is possible for the mind to act and receive impressions, by means of one organ of a determinate structure, and yet be present generally throughout the body.

The facts which we are about to mention prove conclusively that the mind, although its only seat of action is the brain, is itself, nevertheless, not confined to it. Two facts are sufficient. The one is, that animals low in the scale, as Planaria, Polypi, and Annelida, are divisible; and that Polypi and Annelida—for instance, the naïdes and nereides—propagate their species by spontaneous division (see page 28). It is evident from this fact that the vital principle is divisible; but since each portion of the divided animal evinces a separate will and special desires, we have also a distinct proof that the mental principle of these lower animals, whether it be or be not identical with their vital principle, is likewise divisible. The second fact is, that the mental principle in the higher animals also, in man even, is, like the vital principle, in a certain limited sense divisible. The higher animals, and man, do not,

nerate new individuals, each endowed with a mind, by
eir own bodies into several portions; but they do this by
of semen in the male, and the ovum in the female. In
y the generation of the new individual be effected by the
germ of the female and the semen of the male, we know
, frogs, and salamanders, the mere contact of the semen
ught together artificially, without any participation in the
le and female, is sufficient to produce a new individual.
l semen must therefore contain all that is necessary for the
of the independent vital principle and the mental func-
nimal. In one or both of them the vital and the mental
t exist as it were in a latent state; for otherwise these
ld not manifest themselves, as they are observed to do,
er development of the new individual. In the most per-
lso, and even in man, we must suppose that the ovum and
within themselves all the conditions necessary for the
a new being endowed with life and mind; and conse-
ne or both of them contain the vital principle, and the
mind, in a latent state. The main question is not at all
e difference of the new individual being developed within
e mother, as in viviparous, or out of it, as in oviparous,
m the foregoing facts and inferences, therefore, we may
the higher animals and man are so far divisible that a
tion of their matter, namely, the generative fluids (germ
animated with the principles of life and mind; and, this
e, that the mental principle cannot be confined to the
st be contained, although in a latent condition, in parts
distant from the brain, and are separable from the rest of

e vital and mental principles be transmitted from the brain
edium of the nerves to the semen or germ; whether the
nt state be contained in the blood; whether in such a con-
in every part of the body, though free and active only
which is organised as its intrument and apparatus for the
npressions from other parts,—are all questions which it is
answer, and the solution of which would not influence
r present inquiry. It is sufficient for our object to know
and germ must contain not only the vital principle, but
of the new being, in a latent state: thus, that other parts
an the brain participate in being the seat of the mental
ough this principle is manifested only in the brain, on ac-
tructure of that organ being adapted for its action upon
aratus, and to the reception of the impressions communi-
erves. For consciousness, imagination, thought, volition,
ion, the brain is absolutely necessary; and although the
e production of ideas, thoughts, &c. is present in a latent
npregnated germ, yet the whole organisation of the brain
ed in this germ before the mental principle can become
leas, thoughts, and will, be manifested. In the anencepha-
of which the nutrition and life are maintained throughout

the fœtal condition up to the time of birth, the organ generated in the living germ for the future manifestation of the mind has been destroyed (by hydrocephalus) at a period when it was not sufficiently developed to allow the exercise of the mental functions.

From the considerations and facts thus premised, we are now able to determine the question, whether lesions of the texture of the brain modify the mind itself; whether in mental affections the mind or its "essence" can itself be diseased, or whether merely the action of the mind by its instrument be altered. Since, as we have seen, the existence of the mental principle does not depend on an uninjured condition of the brain, and since it is certainly present, although in a latent state, in the germ separated from the parent animal, it is evident that a change in the structure of the brain cannot produce a change in the mental principle itself, but can only modify its actions. The action of the mind is dependent on the integrity of the fibrous structure and composition of the brain. The mode of mental action is always determined by the modification of structure and condition of the organ; but the mental "essence," the latent mental "force," as far as it does not manifest itself, appears to be independent of all changes in the brain. According to this view, all inquiries as to the ultimate cause of affections of the mind, as regards the question of their dependence on the brain or on the mind itself, are useless; and the physician has to keep in view, as the first point in all abnormal conditions of the mental functions, merely the nature of the structural change by which the action is rendered abnormal or prevented. Two cases of congenital idiocy have been reported to us, in which the cranium is so low that the representations given of them call to mind the state of the skull in hemicephalous monsters; but here the cranium is perfect. These idiots are the two sons of a widow named Sohn, living in the colony Kiwitsblott, a German mile from Bromberg; one is aged 17, the other 10 years. Both, enjoying excellent health, are at the same time so stupid that they do not remember their way back to their home if they leave it but a short distance; and cannot unbutton their breeches, although they have full powers of motion and volition in all parts of their body: they manifest their volition only in eating and drinking, and in destroying everything which comes into their hands; they are, however, tractable, and not malicious in disposition. Even in these remarkable cases we cannot imagine that any congenital disease of the mind itself existed—any original defect of the mental principle; in the latent state of this principle in the germ, there was, without doubt, all present which was necessary for the highest perfection; but, on account of the imperfect formation of the brain, the development of the higher mental faculties became impossible. In the same way, in a healthy man, a sudden change in the condition of the brain modifies the manifestation of the mental principle, or even renders it latent; but, if the pressure which impeded the action of the brain be removed, the functions of the mind are frequently restored in their entire integrity.

Since the action of any part always induces a change in the organic
r which composes it, (see page 55,) it necessarily follows that
dinate exertion of the mind, a continued direction of it to one ob-
sequent on external circumstances or great mental excitement,

the organisation of the instrument of the mental opera- hough the removal of these causes may be very important the physician, yet the state of the organ itself is the proper treatment; and the wrong direction of the thoughts is not f the mental disease, but can merely be one among its iting causes.*

n, whether the vital principle by which the whole organi- erm, and even the formation of the organ of the mind, are sentially different from the mental principle, or whether of the mind is merely a mode of action of the vital prin- pable of solution by physiological facts.

f the view, that the mind is merely a particular manifes- al life, may be urged the fact, that it is not confined to one ls, or to man, but is possessed even by the lowest crea- d cannot be denied to any animal which is conscious of s, independent even of external impressions on the senses, ts and desires, forms ideas concerning the objects of these e mode of satisfying of them, and by ideas and desires is oluntary actions. In this sense mental phenomena are n by the lowest animals; the passions are manifested prin- the higher animals. On the other hand, for the opinion l is independent of the vital principle, it may be argued e division of organised living beings, namely, plants, are l mental manifestations. This objection may, however, be pposition, that here the vital principle is in a latent state its mental actions; and when a hypothesis rests merely on a great number of facts, its force is neutralised, if another, an equally good explanation of them, can be opposed to it. estion agitated is, whether the mind be a property of independent power or principle; whether it be a principle united to the body; or whether it be nothing more than , as it were, of a certain condition—of a certain combina-

nena of the mind, whatever be the nature of its essence, oubt closely and necessarily connected with the organisa- in. Unless the complicated fibrous structure of the brain paired state, mind is not manifested in the body; but still it in a latent condition, just as in the generative fluids e new creature endowed with mind is capable.

III. *Of the Medulla Oblongata.*

spinal cord act on each other through the medium of the medulla ence the importance to physiologists of a knowledge of the course of nns or bundles of fibres of this part. Burdach (in his excellent work, *en des Gehirns*,) has thrown more light on this subject than any other following parts are now distinguished as composing the medulla

pyramidalia, formed, according to Burdach, of fundamental and de- The former lie at the anterior surface of the grey central column,

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an writers, as for example, Heinroth, have gone so far as to regard all ng action of the soul, and to speak of the insane as sinners.

and form the posterior wall of the anterior fissure of the spinal cord; but as they ascend in the neck, between the space of 3½ to 1½ inches below the pons, they pass obliquely forwards, so as first to form the lateral boundaries of the anterior fissure, and at last to appear at the two sides of this fissure on the anterior surface of the spinal cord and at the inner side of the anterior columns. The decussating fibres are derived from the lateral columns of the spinal cord, as a branch of which they run behind the olivary body on each side, ascend, passing obliquely inwards and forwards, and with the former set of fibres appear at the surface of the cord one inch below the pons Varolii, at the side of the anterior fissure. The decussating fibres alone pass from one side of the fissure to the other to join the fundamental fibres of the opposite pyramid. (*Burdach*, ib. ii. 31.) The fibres of the corpora pyramidalia pass between the transverse fasciculi of the pons to reach the crura cerebri.

2. Fasciculi of fibres which run at the inner and outer side of the olivary bodies, and which are not seen on the surface of the medulla oblongata. (Fasciculi siliquæ. Burdach.) The more anterior or internal of these fasciculi is formed of the fibres which bounded the anterior fissure of the spinal cord, and which have been thrust outwards by the corpora pyramidalia rising to the surface. The external fasciculus is the outer portion of the anterior column of the spinal cord which lay at the inner side of the anterior roots of the nerves. Both these fasciculi, which sheath the olivary bodies, are in contact with each other till they reach these bodies. The internal fasciculus passes with the pyramids through the pons into the crura cerebri. The external is continued upwards and inwards, around the upper portion of the processus cerebelli ad testes, to the base of the corpora quadrigemina.

3. The olivary body is formed by the expansion of the anterior grey column of the cord. At this point the grey column forms a plicated vesicle of grey matter, filled internally as well as invested externally with white fibrous substance. This it is which produces in a section of the corpus olivare, the appearance called corpus dentatum.

4. The lateral column of the spinal cord gives off from its inner side at the commencement of the medulla oblongata the decussating fibres of the anterior pyramids; the remaining portion is continued over the olivary body into the processus cerebelli ad medullam oblongatam (corpus restiforme), and partially also into the external part of the fourth ventricle. (*Burdach*, ibid. p. 35.)

5. The fasciculus cuneatus is the continuation of the medullary fibres which cover the posterior grey columns of the spinal cord, and which, lying at the upper side of the lateral column, form with it the process from the medulla oblongata to the cerebellum; its internal fibres run at the outer part of the walls of the fourth ventricle towards the cerebrum. According to Mr. Solly, some fibres of the anterior columns also of the spinal cord contribute to form the corpus restiforme, or processus cerebelli ad medullam oblongatam, interlacing in it with those derived from the lateral columns.

6. At the inner and posterior surface of the corpus restiforme lies a delicate fasciculus of fibres (fasciculus gracilis), the inner side of which forms the lateral wall of the posterior fissure, and is, in part, in close contact with the corresponding surface of the fasciculus of the opposite side. At the apex of the fourth ventricle, this fasciculus becomes swollen into a club-shaped body (clava). (*Burdach*, loc. cit. p. 37.)

7. The "round fasciculi" (fasciculi teretes) are rendered visible by the divergence of those last described; as lateral walls of the canal of the spinal cord they lie between the corpora restiformia in the floor of the fourth ventricle, and pass forwards, separated by the medium fissure, to form the anterior and inferior boundary of the aqueduct of Sylvius.*

Properties of the medulla oblongata.—It has the general properties of the medulla spinalis. It has the same property of reflection, indeed in a higher degree than any other part of the nervous system; and the

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* For a full detail of the course of the fibres in the brain I refer to Burdach's work; and to the "Icones" of Langenbeck, for an account of the later investigations into the structure of the brain. Weber's edition of Hildebrandt's Anatomie, M. D'Alton's article in the 11th volume of the Encycl. Wörterb. der Medicin. Wissench. (Mr. Solly's work on the Brain, and the excellent Tabulæ Anatomicæ of Arnold, as well as his Bemerkungen über den Bau des Gehirns, &c. Zurich, 1838,) may be consulted.

arise from it are more prone than any other nerves to
It belongs also to the motor apparatus, and no other
eat an influence on the production of motions, for irrita-
tes convulsions of the whole trunk, and by lesion of it the
s paralysed. But the properties which especially distin-
lulla oblongata are the following:—
source of all respiratory movements, as has been shown
of the natural movements of respiration, and of the spas-
on of the respiratory muscles excited by irritation of the
ranes (see page 323). The passions, in exciting the respira-
e facial included), act through the medium of the medulla
The same movements, as laughing, crying, and yawning,
ently excited by the influence of the sensorium occupied
as on the medulla oblongata.
seat of volition.—The experiments of M. Flourens show
in which the cerebral hemispheres have been removed,
tate of stupor, are still capable of executing voluntary
nd they have still the power of volition after the removal
lum also, but by this last mutilation their movements are
rce and co-ordination.*
lulla oblongata is the seat of the faculty of sensation.—
erely shown by the anatomical fact that all the cerebral
he exception of the first and second, are connected with
prolongations in the brain; it is proved also by the history
ts on the different parts of the encephalon. From the re-
agendie and Desmoulins it results that the removal of the
spheres and the cerebellum does not deprive an animal
of sensation. The central organs of the senses of sight
lost with the cerebral hemispheres, and blindness ensues;
iousness of sensations does not appear to be the function
m. Flourens concluded from his experiments that the
spheres are alone the central organ of sensations. But
gitimate inference from his highly interesting observa-
n fact, as Cuvier has remarked (in his Report to the Aca-
Memoir of M. Flourens), prove directly the contrary. An
ch the cerebral hemispheres have been removed is in a
; but presents, nevertheless, manifest signs of sensibility,
y of the reflection of impressions. It no longer performs
movements; but, when struck, it has all the manner of
ing from sleep. In whatever position it be placed, it re-
ilibrium. If laid upon the back, it rises again; if pushed,
t be a bird, and we throw it up into the air, it flies; if it
aps when touched. The animal has, doubtless, lost its
o longer reasons; but nevertheless it feels, and the sensa-
it movements which are different from the phenomena
ous reflection. Cuvier very aptly compares animals in

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nt of anencephalous monsters which have performed voluntary move-
r's Archiv. 1834, p. 168. Compare also the remarks on the same
rainger, on the Spinal Cord, p. 79, et seq. and Dr. Hall, in his Ne-
vous System.

this condition to a sleeping man; he also seeks an easy position; he feels.*

Sensation itself must be distinguished from "attention," (the direction of the mind to sensations,) and from the faculty of forming ideas from sensations. Attention appears to be a function of the cerebral hemispheres; by their removal the animal is rendered stupid, though sensation remains. Among a certain number of simultaneous sensations we are able to direct our attention to a single one, so as to perceive it, not only more distinctly than the rest, but definedly and in its whole intensity; this sensation excites in us ideas, while those to which attention was not directed are perceived, but only indistinctly. While, therefore, the medulla oblongata is susceptible of obscure sensations, the distinct perception of sensations is dependent on parts of higher function, which are lost when the cerebral hemispheres are removed.

Some have believed that the medulla oblongata is the central organ for all sensations. This appears to me to be an error, if by medulla oblongata be meant only the superior enlarged portion of the spinal cord, and not also its prolongations into the cerebrum. The medulla oblongata, in the restricted sense, is certainly the receptacle for all the sensations of touch; these sensations are felt even after the cerebrum is removed,—though indistinctly, owing to the mind not being directed to them. On the other hand, for the senses of sight and smell there are central organs which lie in the cerebral hemispheres: blindness, for example, is produced by mutilation of the anterior pair of the corpora quadrigemina, of the thalamus opticus, or of the deep-seated parts of the hemispheres generally. It appears, therefore, that the central organs of the different senses are independent of each other; if they do in part belong to the prolongations of the fasciculi of the medulla oblongata, still it appears that their actions may be isolated, while a reciprocal action of each with the hemispheres of the brain is necessary for a distinct perception of the sensation of which it is the seat. This is probable, but many facts are wanting to prove it. It appears certain that, after the removal of the central organ of vision, the impressions on the nerves of common sensation are still felt; but it is not known whether, after the destruction of the medulla oblongata, impressions on the other senses can still be perceived. Injury to the medulla oblongata puts a stop to respiration, and thus reduces life to such a low ebb that it is impossible to institute experiments as to the persistence of the sensations of sight, smell, &c. It is, however, most probable that the actions of the different organs of the senses are ultimately communicated to the cerebral hemispheres, and not to the medulla oblongata, and that it is in them that the separate sensations are converted into ideas.

With reference to the sense of hearing, it is usually supposed that its central organ is the floor of the fourth ventricle, since the fibres of the auditory nerve have their origin there. Flourens, on the contrary, maintains that, after the removal of the cerebral hemispheres (which birds survive many months), hearing is lost. But whether the sense of endent on a state of integrity of the floor of the fourth , the transverse white fibres which are seen on it appear means the important influence on the sense of hearing attributed to them; they are by no means constantly con- auditory nerve, and sometimes pass distinctly over the of the nerve into the crus cerebri. In the Museum at the brain of a young female, who, in consequence of a eck and occiput, was gradually attacked by paralysis of y; and here, upon the floor of the fourth ventricle, and nsverse white fibres, an effusion of lymph had taken the sense of hearing had not suffered. (See *Fischer, ephalitidis Casu.* Berol. 1834.)

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* See Cuvier's Rapport, &c. in M. Flourens' work, Sur les propriétés et les fonctions du Système Nerveux. Paris, 1824, p. 77.

IV. *Of the Corpora Quadrigemina.*

quadrigemina of Mammalia, and the lobi optici of birds, ibia, and fishes, belong, with the optic thalami of the , to the central apparatus of the sense of vision. It is lourens, that if in a pigeon one of the lobi optici be re- a mammiferous animal one-half of the corpora quadri- ess of the eye of the opposite side is produced, though the iris is preserved for a long time. (M. Magendie did this result in Mammalia.) According to MM. Magendie ns, the animals turn frequently upon their own axis, side on which the removal of the optic lobe has been movement, which was observed even in frogs, appears lt of vertigo. Flourens covered one eye in healthy hey turned round in a similar way; but not so briskly, er time. The removal of the optic lobe is always at- vulsions of the opposite side of the body, of which the r is afterwards much impaired. It is a remarkable fact ry to one of the optic lobes always destroys the sight of e, yet the contractility of the iris under the influence of st if the mutilation be only superficial; a complete re- tic lobe paralysing the iris as well as the sense of sight. ins this on the supposition that a partial removal of the s not abolish the excitability of the optic nerves, because troy all their roots. The motion of the iris is certainly he excitation of the optic nerves by light; for Flourens tation of these nerves caused the iris to contract, and m paralysed its motions. The explanation given by ect; but, when the optic lobe is partially removed on he action of light on the retina which is not paralysed e contraction of the iris of the blinded eye. The re- Hertwig (*Exp. de effect. læsion. in partibus Encephali.* have afforded a confirmation of the experiments of nost every particular. The results which M. Hertwig . that the partial mutilation of one-half of the corpora r optic lobes in Mammalia and birds produces partial and blindness of the opposite side of the body,—that , is regained after a certain time; 2. that this partial lesion does not abolish the motion of the iris,—on the contrary, that these motions sometimes continue; 3. that by removing a larger portion of the optic lobe, or completely extirpating it, vision, as well as the contractile power of the iris, is completely destroyed; 4. that mutilation of the optic lobe has nearly the same effect on the eye as injury to the optic nerve; 5. that the muscular weakness of the opposite side of the body, produced by the mutilation of one optic lobe, is only temporary; 6. that the infliction of this injury on one side of the body, causes the animal to move round on its axis, as if giddy; 7. that no other effect than those mentioned follow the mutilation of the corpora quadrigemina,—thus, for example, that no disturbance of memory or consciousness is produced.

The only point in which the observations of this experimenter differ from those of M. Flourens, has reference to the convulsions produced by injury to the optic lobes, which, in M. Hertwig's experiments, never ensued. The opposite result obtained by M. Flourens was perhaps due to his incision being carried too deeply.

V. *Of the Cerebellum.*

The functions of the cerebellum have been made the subject of interesting experiments by Rolando, Flourens, Magendie, Schoeps, and Hertwig.

M. Rolando constantly observed that the diminution of the movements was in a direct ratio with the lesion of the cerebellum; that stupor was never produced, nor the sensibility of any part of the body impaired; but that the power of the muscular movements was lost. The animals kept their eyes open, and regarded surrounding objects, but in vain endeavoured to execute any of the movement necessary for locomotion. An animal in which one side of the cerebellum had been removed, fell upon the same side, not being able to support itself upon the leg of that side. These results induced Rolando to adopt a supposition quite incapable of proof, namely, that the cerebellum is the organ destined for the generation of the nervous principle, which he compared with electricity; and that the alternate layers of white and grey substance of the cerebellum act, as Reil also imagined, in the way of a galvanic pile.

The experiments of M. Flourens (*Loc. citat.* pp. 18 and 36,) are more lucid and more decisive in their results. He found that the animals evinced no signs of sensibility in the cerebellum while it was being removed. He extirpated the cerebellum in birds by successive layers; feebleness and want of harmony of the movements were the consequence. When he had reached the middle layers, the animals became restless without being convulsed; their movements were violent and irregular, but their sight and hearing were perfect. By the time that the last portion of the organ was cut away, the animals had entirely lost the powers of springing, flying, walking, standing, and preserving their equilibrium. When an animal in this state was laid upon the back, it could not recover its former posture; but it fluttered its wings, and did not lie in a state of stupor; it saw the blow which threatened it, and endeavoured to avoid it. Volition, sensation, and memory, re not lost, but merely the faculty of combining the actions s in groups; and the endeavours of the animal to maintain m were like those of a drunken man. The experiments ame results when repeated on all classes of animals, and lourens infers that the cerebellum belongs neither to the to the intellectual apparatus; and that it is not the source movements, although it belongs to the motor apparatus: of wounds on it does not, however, he says, excite convul- n other motor apparatus, such as the spinal cord and me- ta, are wounded;—but the removal of it destroys the force nents, and the faculty of combining them for the purposes ,—the faculty of the co-ordination of the movements. If correct, the cerebellum must contain a certain mechanism he excitement of the combined action of muscles, so that ance of its structure must destroy the harmony between gan of combined motions, and the groups of muscles with

It is also to be remarked, that injury to the cerebellum ces its effects on the opposite side of the body.

rvations of Flourens have been confirmed by Hertwig, at the cerebellum itself was insensible; that irritation of convulsions; and that though lesion of it interfered with ion of movements, the senses and all the other functions reby affected. Hertwig, however, remarked, that if the the cerebellum had been partial only, its function was also found that removal of one side of the cerebellum movements of the opposite side of the body.

lie states that hedgehogs and guinea-pigs, in which he had th cerebrum and cerebellum, rubbed their nose with their vinegar was held to it. He asserts, also, that, when the inflicted on the cerebellum, the animal made an effort to was compelled by an inward force to retrograde. Injury *rebelli* or *processus ad pontem*, and of the pons itself, upon ays caused the animals to roll over towards that side. The as produced by every vertical section which involved the ass lying over the fourth ventricle, but it was seen in the degree as the result of injury of the crus. Sometimes, says, the animals made sixty revolutions in a minute, and this movement continued for a week without cessation. t convulsive movements, but are voluntarily performed, the influence of an internal impelling force, or as if the attacked with vertigo. Division of the second crus cere- l by M. Magendie to restore the equilibrium. Hertwig l in a dog in which the pons Varolii was wounded on the t similar revolutions of the body towards the same side ed, and one eye was turned upwards while the other was wards. Superficial wounds of the pons were, in Hertwig's attended with moderate pain; he believes each half of the nce the opposite half of the body. No convulsions were itating it.

rm bodies belong to the medulla oblongata; injury inflicted on one of them in a goat was found by Rolando (*Saggio, &c.* ed. 3, p. 128,) to produce convulsions, with curving of the body of the animal to the injured side. Wound of the *processus cerebelli ad testes* was observed by the same author to cause convulsions which affected in the greatest degree the extremities of the opposite side of the body; the animal, a rabbit, fell upon the side on which the lesion was inflicted each time that it made a spring.

Gall regards the cerebellum as the organ of the sexual impulse. The grounds on which this view is founded are not conclusive. Burdach (*Op. cit.* iii. p. 423,) has collected the facts which bear upon this question. He has calculated that affection of the sexual passion is observed once in every seventeen cases of lesion of the cerebellum, and once in three hundred and thirty-two cases of lesion of the cerebrum. In apoplectic cases attended with erection of the penis, there has been found effusion of blood in the cerebellum.* Dunglison† observed priapism in a case of inflammation of the cerebellum with serous effusion. Destruction of the spinal cord in animals also gives rise occasionally to erection of the penis. The observations of Heusinger, (*Meckel's Archiv.* vi. 551,) that, in two birds which died suddenly, there was a turgid state of the testicles and effusion of blood in the cerebellum, cannot be adduced as proof of the correctness of Gall's hypothesis; and all the other cases of simultaneous disease of the cerebellum and affection of the sexual functions do not really prove much. The coincidence of disease of the spinal cord with affection of the genital organs is much more frequent.‡

The development of the cerebellum in the scale of animals presents no relation with the energy of the sexual impulse. In the Amphibia (as frogs and toads) this organ is extremely small, constituting a mere band lying over the fourth ventricle, and nevertheless the sexual instinct of these animals has become proverbial, although they have no erectile organ.

A preparation in the anatomical museum at Bonn (see *Weber, in the Nova Act. Nat. Cur.* xiv. p. 111,) is unfavourable to Gall's opinion. It is the cerebellum of a man in whom half the organ was found atrophied. Death had been caused by an inflammatory disease. But the sexual passion had been rather strong than weak; the man was married, and the father of several children. The facts detailed by Cruveilhier (*Anat. Pathol.* livr. xv. 18,) are, however, the most remarkable. In one case, an individual twenty-one years of age, two large tuberculous masses were found in the left hemisphere of the cerebellum, although

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* Serres, in Magendie's Journ. iii. p. 114. † Lond. Med. Reposit. Oct. 1822.

‡ M. Budge (Müller's Archiv. 1839, p. 390) states as the result of repeated experiments, that irritation of the cerebellum with the point of a knife in a cat just killed causes the testicle of the same side to move, so as to place itself more at right angles with the vas deferens. The fact, if confirmed, would be curious. But M. Budge draws conclusions so hastily from his observations, that he excites the suspicion of his experiments having been performed with equal want of care.—*Translator.* (See for details on this head, and of a discussion, in the French Royal Academy of Medicine, on Phrenology, Stokes & Bell's Lectures on the Practice of Physic, p. 445 and p. 438–41, vol. ii. 2d edit.)

en no paralytic symptoms, no pains in the head, and no
natural phenomena in the genital organs. Since the sub-
isease is said to have had no desire for sexual pleasures,
ht be regarded as a proof of the correctness of Gall's hypo-
e second case, however, there was coincidence of complete
cerebellum with tendency to masturbation; it occurred in
ven years. When seven years old, she presented great
the extremities, want of intelligence, and indistinct articula-
eleventh year, when she was more closely observed, the
the extremities was so great that she could scarcely move
ough their sensibility was perfect. She could move her
ntellect was very dull. After death, which was caused by
tory disease, the inferior occipital fossæ were found filled
In place of the cerebellum there was merely a membran-
ssing transversely over the medulla oblongata, and con-
ach side with a swelling of the size of a hazel-nut. The
was entirely absent, the olivary bodies indistinct.*(*a*)

VI. *Of the Cerebral Hemispheres.*

f the cerebral hemispheres having a more perfect develop-
portion as the animals in which we examine them are
scale of Vertebrata from fishes up to man, and the co-
atrophy and absence of the convolutions on their surface
are alone sufficient to indicate that the seat of the higher
culties must be sought in this part of the encephalon. It
r, been proved by direct experiment that such is their seat.
ents of Flourens are here also especially instructive, and
in the essential points done no more than confirm them.
eres are insensible both to puncture and incisions. That
rain in which the sensations are converted into ideas, and
rded up, to appear again, as it were, as shadows of the sen-
elf devoid of sensibility. This result, confirmed by Hertwig,
vise with the phenomena observed in wounds of the head
it has been very frequently remarked, when it has been
separate protruded portions of the brain from the healthy
s has given rise to no sensation even in persons whose mind
clear. Wounds of the hemispheres give rise moreover to
ns; the only constant effect of a deep incision is blindness
the opposite side and a state of stupidity. Haller and Zinn
that injury to the upper part of the cerebral hemispheres
muscular contractions. No contractions of muscles are
rding to Flourens, by irritating the *corpora striata* or the
i; and the same fact had been already ascertained by M.
reference to the *corpus callosum.*

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presentation of the parts in Cruveilhier, livr. xv.
n of argument pursued by the author in the text, to disprove the phreno-
a of the cerebellum, is that of the pure spiritualists, who assert, that
k and reason without a brain, because, say they, he sometimes exercises
is way, nothwithstanding serious lesions and losses of substance of
y the same showing, the lungs are not the organ of respiration nor the
f digestion.

The general results of the experiments of Flourens and Hertwig on different animals, relative to the function of the cerebral hemispheres, are very similar. I will recount the very interesting details of an experiment instituted by Flourens on a pigeon. The right hemisphere, being removed, the pigeon was found to be blind in the opposite side. The contractility of the iris, however, still continued (see page 623). There was a marked feebleness of all parts of the left half of the body. This, however, is, according to M. Flourens, a very variable phenomenon both as to its degree and duration. In all animals the forces soon recover their equilibrium, and the disproportion between the two sides disappears. The pigeon saw very well with the eye of the injured side, it heard, stood, walked, flew and did not appear uneasy.

In another pigeon both cerebral hemispheres were removed; loss of vision immediately ensued, with general loss of power, which, however, was neither considerable nor persistent. The pigeon flew when it was thrown into the air; walked when it was pushed. The iris had its power of motion in both eyes;* the animal was deaf, and it did not move spontaneously, but had constantly the manner of a sleeping animal, and when irritated it resembled in its motions an animal just awaking. In whatever position it was placed, it resumed its equilibrium; if laid upon the back, it got upon its feet again; water being put into its beak, it swallowed it; and it resisted attempts to open its beak. M. Flourens likens the pigeon in this condition to an animal condemned to perpetual sleep, but deprived even of the faculty of dreaming. Experiments on Mammalia were attended with similar results.

The experiments of Hertwig confirm M. Flourens' observations. Wounds of the hemispheres (in a dog) excited no pain, unless they extended to the base of the brain, when signs of pain were exhibited. M. Hertwig removed both hemispheres in a dog: the animal did not move from the post voluntarily, but was thrown into a state of complete stupor; if irritated, it moved a few steps, and then fell again to the ground in a sleepy state. It did not hear even the report of a pistol. M. Hertwig removed the upper part of the hemispheres in a pigeon; sight and hearing were abolished, and the animal sat in one spot as if asleep. He fed it: peas, if placed merely within the beak, were not swallowed; but if laid upon the tongue, they were (owing to reflex action); the muscles were but slightly enfeebled; the bird stood firmly, and flew when thrown into the air. This state endured for a fortnight, when the hearing and sensibility in a great measure returned; this pigeon lived three months. A hen, in which Hertwig had cut away both hemispheres nearly to the

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* Mr. Grainger explains this phenomenon in accordance with Dr. Hall's theory of the existence of special fibres for reflex motions to which the contraction of the iris under the influence of light belongs. "The optic nerve," he says, "contains two orders of fibres; the true sensiferous, which are connected with the cerebral convolutions, by the diverging fibres described by Spurzheim, and the incident fibres attached either to the grey matter of the optic tubercles, or of the optic thalami." When merely the cerebral hemispheres are removed, the latter fibres must remain intact, and will, therefore, when excited, according to Mr. Grainger's conjecture, by the calorific rays of light, determine the contraction of the pupil through the medium of reflex fibres of the third nerve.

brain, was found to be deprived of sight, hearing, taste, and
constantly in one spot, and was as if dead until strongly
n it moved a few steps. The animal lived in this state of
out its senses being restored, for three months.
ps (*Meckel's Archiv.* 1827,) has instituted similar experi-

nt from these experiments, and from the effects of pressure
ral hemispheres in man, that they are the seat of the mental
at in them the sensorial impressions are not merely per-
re converted into ideas; and that in them resides the power
the mind to particular sensorial impressions,—the faculty
) In what respect the medullary and the grey substance of
eres differ with regard to function, we are quite ignorant.
r of the mind in different animals manifestly increases *pari*
he extension of the surface of the cerebral convolutions;
not the slightest knowledge of the nature of the influence
e grey cortical substance into which the innumerable fibres
hrough the optic thalami at last radiate. We are ignorant
e of the change produced in the medullary fibres in the
ance, or in the principle which animates it, when an idea
pression on the highly susceptible substance of this wonder-
We know only, that every idea is a permanent immutable
the brain, which may at any moment present itself anew
be directed to it,—if the "attention" be turned to it; and
rely the impossibility of the attention being occupied by
s simultaneously, that causes each to be forgotten. All
deas must be regarded as impressions on the brain which
aced. Lesions of the brain may annul a part or all these
, in such cases, persons have lost their memory for nouns,
n for the occurrences of certain periods of their life; and
thus lost has sometimes returned again. The direction of
ne single idea modifies the co-existence and disturbs the
f all the rest; hence, if the relative strength of the different
ere known, it would be almost possible to calculate what
ould be excited by another known image.
ble that there is in the brain a certain part or element appro-
e affections, the excitement of which causes every idea to
ntensity of emotion, and which, when very active, gives
hought, even in dreams, the character of passion; but the
such a part or element cannot be strictly proved, nor its
nstrated. Still less can it be shown that, independently of
ent of the mind, the particular tendencies of the thoughts
have their special seat in distinct districts of the hemi-
is view, advocated by Gall, which forms the ground-work
e of cranioscopy or phrenology, does not, it is true, involve

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ns of the different parts of the encephalon have been lately investi-
ntally by M. Nonat (see Gazette Medicale, Oct. 19, 1839), but appa-
bringing to light any important new results. An account of some
ents by Magendie is contained in his Leçons sur la Système Nerveux.

any impossibility; but there are no facts calculated in the slightest measure to prove the correctness of the hypothesis generally, or the correctness of the details of the doctrine founded upon it. No part of the brain can be distinctly pointed out as the seat of memory, of imagination, &c.(*a*) Memory may be lost as a consequence of lesion of the hemispheres at any part of their periphery; and the same is the case with regard to all the principal faculties or tendencies of the mind. On the other hand, with regard to the "faculties" set down by Gall, a part of which are totally unpsychological, we may at once exclude from the forum of scientific researches these arbitrary dogmas, which can never be proved. The remark made by Napoleon to Las Cases, with reference to Gall's system of phrenology, is very interesting: "He ascribes," said Napoleon, "to certain prominences, propensities and crimes which do not exist in nature, but are the growth of society, and are merely conventional. What would the organ of theft effect, if there were no property; the organ of drunkenness, if there were no spirituous liquors; or the organ of ambition, if there were no society?" Gall's system includes no organ of drunkenness; but still the remark is correct as far as regards the bad psychological foundation of the organ marked out by Gall. It does not, however, overturn the principle of phrenology; but only the mode in which it is carried out.

With regard to the principle, its possibility cannot, *à priori*, be denied; but experience shows that the system or organs proposed by Gall has no foundation; and the histories of injuries to the head are directly opposed to the existence of special regions of the brain destined for particular mental faculties. Not only may both the higher and lower intellectual faculties—as reflection, imagination, fancy, and memory—be affected by lesion of any point on the surface of the hemispheres; but it has been frequently observed that different parts of the hemispheres may aid the action of other parts in the intellectual functions, and frequently where the removal of portions of the surface of the hemispheres has become necessary in the human subject, no change in the moral and intellectual powers of the individual has ensued.(*b*)

It appears, with regard to their action in the intellectual functions, that the one hemisphere can perform the office of the other. Cases, at least, have been observed in which permanent disease of one hemisphere has left the mind unimpaired; and Cruveilhier (*Livraison*, viii.) has related a case of atrophy of the entire left half of the cerebrum in a man forty-two years of age, in which the atrophied hemisphere was only about half as large as the sound one, all its parts—the crus cerebri, corpus mammillare, thalamus opticus, corpus striatum, and lateral ventricle,—being all equally diminished in size, and nevertheless the mind was perfect. The two halves of the cerebellum were nearly equal in

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(*a*) Gall and the phrenologists generally regard memory and imagination, not as separate faculties, but as modifications of any one intellectual faculty. Of course, they do not suppose that there is a seat in the brain for either memory or imagination separate from the faculty to which they belong.

(*b*) The author forgets that the very next sentence, in which reference is made to Cruveilhier's case, affords an answer to this objection against phrenology, p. 632. Of a similar import are the last two paragraphs of the present division of this chapter.

at being only a little smaller than the left. In this case the
the body had been from youth upwards partially paralysed,
ng still able to walk with a stick; and the limbs of the weak
asted.

nissures appear to be the cause of this unity of action of the
neres. The influence of the corpus callosum is not quite
the presence of the corpus callosum and fornix would ap-
case observed by Reil, (*Archiv.* xi. 341,) not to be neces-
exercise of the lower mental faculties. In a woman whose
re dull, but who was nevertheless capable of common oc-
ich as going on errands, the parts mentioned were wanting,
er commissures were present. The coincidence of idiocy
tion of the corpus callosum in chronic hydrocephalus does
ny connection between them, the disease being so compli-
tumours and hydatids have been found attached to the
um in idiots; and La Peyronnie observed loss of memory
sion of that part of the brain.* Few direct experiments
stituted with a view to determine the function of the cor-
l. Saucerotte divided this part in a dog; stupor, with vio-
; and hiccough, were the result. The animal saw and
ad lost the sense of smell, and the sensibility of the ears,
uscles. (See *Burdach, Op. cit.* iii. 486.) Rolando (*Saggio,*
performed the same experiment on a goat. The animal
ne time without moving, then became restless and ran for-
was kept two days; by degrees it became feeble, could
on its legs; and its whole body trembled and was cold.

ions of the pituitary and the pineal gland are, we may say,
nown. Greding, it is true, frequently found disease of the
nd in cases of mental affections; but, in such cases, disor-
ave been met with in all parts of the brain. Wenzel ob-
se in the pituitary gland frequently in epileptic subjects.†
esis of Descartes, that the pineal gland is the seat of the
en long relinquished and forgotten. It is, according to
servation, seldom affected in lunatics. (See *Burdach*, op.
7.)

s of pathological anatomy can, however, never have more
d application to the physiology of the brain. We are unac-
h the laws according to which the different parts of the

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lisease of the corpus callosum will be found collected in the works of
ologie. vi. p. 258; and Burdach, Op. cit.

in a Memoir presented to the Académie des Sciences on Oct. 24, 1839)
escribed nervous filaments arising from the anterior and posterior sur-
itary gland, and anastomosing with the carotid and cavernous plexuses
etic; and has named it in consequence of these connections the cephalic
s difficult to say what importance should be attributed to these observa-
zin; for only a short time previously M. Rathke had described the de-
he pituitary gland as taking place by the protrusion upwards of the
ane of the mouth, so as to form a diverticulum projecting into the base.
which subsequently becomes cut off from the buccal cavity, and at the
ches itself to the infundibulum of the brain. (See Müller's Archiv.
nd 1839, p. 227.)

organ participate in the functions of each other; and we can only in a general way regard as certain, that organic diseases in one part of the brain may induce changes in the function of other parts; but from these facts, and the results of pathological anatomy, we cannot always draw certain conclusions. Degenerations in the most various parts of the brain, which appear from experiment to have no immediate connection with the central organs of the sense of vision, nevertheless frequently cause blindness; and at this we must be the less surprised, since, even in diseases of the spinal cord, as tabes dorsalis, imperfect amaurosis is a frequent symptom.

The same remark applies to the relation of lesion of the different parts of the brain to mental diseases; the brains of insane persons frequently presenting degeneration in parts which are not the essential seat of the intellectual functions. Abundant confirmation of what we have here said is afforded by the collection of cases, and the calculations which Burdach has given, relative to the coincidence of disease of different parts of the brain with certain changes of the functions. It must be further remarked, that a chronic disease, which acts merely by exerting pressure, and does not produce complete atrophy, may, by its gradual development, prepare and accustom the depressed parts to its presence. Hence the great difference between the effects of chronic and those of sudden lesions of the brain. Thus important parts may be pressed upon without their functions being essentially disturbed; as in a case detailed by Cruveilhier, in which the pons Varolii and the crura cerebri were compressed by a pearl-like fatty tumour of slow growth, although neither the power of motion nor sensation was affected.

VII. *Of the Laws of Action of the Brain and Spinal Cord.*

We have here to consider the laws according to which nervous actions are propagated in the fibrous structure of the brain and spinal cord. Our knowledge is on this subject as imperfect as it is complete with reference to the propagation of nervous action in the nerves. The primitive fibres of a nerve lying in the same sheath do not communicate their particular states from one to another; their action is propagated in each in an isolated manner from the periphery to the central organs, and from these back again to the periphery. If, as we have shown to be probable, these fibres be tubes containing nervous matter, the walls of the tubes would appear to have an insulating relation to the action of their contents. On the other hand, in the brain and spinal cord, the nervous matter is not contained in such distinct tubes; and between the fibres there is, particularly in the grey substance, a granular matter, which appears to facilitate the communication of influences from one fibre to another, even where no anastomosis of fibres exists. Hence, perhaps, the proneness to the propagation of a particular state of one part of the brain and spinal cord to another part, and the phenomena of the reflection of impressions from the origin of sensitive roots upon the contiguous motor roots of the nerves. Still, however, the propagation of nervous action in the fibres of the spinal cord generally follows more readily the direction of the fibres than any other course; otherwise the excitation of the roots of particular nerves to motor action, and the in-

brain on the nerves of the opposite side of the spinal cord,
possible. The laws of action of the grey substance in the
brain and spinal cord, and on the surface of the brain, are
Ve must also be content to exclude from consideration the
the fibrous structure of the brain in all the intellectual

ady considered the phenomena of the reflection of nervous
ensitive upon motor fibres through the medium of the
explanation of which is afforded by the structure of the
r of the brain, we have here to investigate the motor
the central organs, and still more the paths of the propa-
ations and motions, and the crossing of the sensitive and
es in them.
d to the motor apparatus, we must distinguish between
when wounded, excite convulsions, and those, the mutila-
diminishes the motor power without causing muscular
e. This is an important distinction, which we owe to
must, at a future period, have a great influence on the
erebral diseases. Experiments of M. Flourens and M.
that the first class of motor apparatus includes only the
igemina, the medulla oblongata, and the spinal cord; to
belong all the other motor apparatus of the encephalon,
ptic thalami, the corpora striata, and the cerebrum gene-
it has any motor influence, the pons Varolii and the cere-
njuries inflicted on these parts, the power of motion is
no convulsions are excited; while injury to the medulla
spinal cord infallibly excites convulsions. Although,
g to the reaction of different parts of the brain on each
able that other parts than the corpora quadrigemina and
gata may, in disease, excite convulsions by sympathy;
thology teaches us that such is the case; yet, from the
ntioned, we may infer that, when the power of motion
defective from disease in the central organs, the cause
either in the corpus striatum, thalamus opticus, hemi-
cerebellum, medulla oblongata, or medulla spinalis; but
f convulsions, or convulsion with paralysis dependent on
brain or spinal cord, the seat of the disease is more likely
ra quadrigemina, spinal cord, or medulla oblongata, than
of the nervous centres.
ortant circumstance with reference to the laws of action
d spinal cord, is the crossing of the nervous actions in
experiments on animals, and pathological observations, it
ions of the spinal cord and medulla oblongata always
ons or paralysis on the same side of the body. This is
le in the case of the spinal cord, for in it there is no
the fibres of the two latter halves; but, with reference
a oblongata, the above result of the experiments of
Hertwig is not perfectly consonant with the anatomical
e part; for since, in the medulla oblongata, the fibres of
ramidalia certainly decussate, while those of the other

fasciculi continue their course on the same side of the spinal cord, it would be expected that, according to the part of the medulla oblongata affected by the lesion, the consequences would be observed on the opposite or on the same side of the body. M. Lorrey had, indeed, observed that when wounds were inflicted upon the medulla oblongata, the convulsions were constantly on the same, the paralysis on the opposite side of the body. To this result, however, those of the experiments of Flourens and Hertwig are directly opposed; but we must recollect that their experiments were instituted principally on the lateral fasciculi only which do not decussate; and it is very probable that, if the corpora pyramidalia be wounded above the decussation of the fibres, the effects produced would be seen on the opposite side of the body. Injuries inflicted on the cerebellum, the corpora quadrigemina, and cerebrum are always productive of loss of power on the opposite side; and mutilation of the hemispheres and corpora quadrigemina, of blindness of the eye of the opposite side. Such is the general result of the experiments of Flourens and Hertwig. With reference to the cerebral hemispheres, it had been already proved, partly by experiment, and partly by pathological observations by Caldani, Arnemann, Valsalva, Wenzel, and others. (See *Treviranus*, *Biologie*, vi. p. 117.—*Burdach*, loc. cit. iii. p. 365.) M. Magendie has come to the same conclusion with regard to the cerebral hemispheres; and by extirpation of one eye in birds he has produced atrophy of the opposite optic lobe. The influence of injury of the corpora quadrigemina, is, according to M. Flourens, produced both in the anterior and in the posterior direction on the opposite side; anteriorly in the eyes, posteriorly in the other parts of the body. Pathological observations confirm, for the most part, these results; the rare exceptions which have been met with are collected by Treviranus and Burdach. According to Burdach's calculation, in two hundred and sixty-eight cases of lesion of one side of the brain, ten presented paralysis on both sides of the body; and two hundred and fifty-eight, hemiplegia, in only fifteen of which was the paralysis on the same side as the lesion. The convulsions were in twenty-five cases on the same side as the disease; in three cases, on the opposite side.

These facts explain the origin of a dogma which has prevailed since the time of Hippocrates, namely, that in wounds of the brain the convulsions occur on the wounded, the paralysis on the opposite side. In fact, if the wound have a certain direction, it may produce both these effects at the same time, by implicating different parts. No one has contributed to elucidate these difficulties so much as M. Flourens: he has shown that injury of the spinal cord and medulla oblongata causes paralysis and convulsions on the same side, and injury of the corpora quadrigemina paralysis and convulsions on the opposite side; while injury of the thalami, corpora striata, and hemispheres of the cerebrum and cerebellum, induces paralysis on the opposite side of the body without convulsions. If both cerebellum and medulla oblongata were wounded simultaneously on the same side, paralytic weakness of the opposite side, and convulsions and paralysis of the same side as the injury, were the consequence. Although Flourens (*Sur le Syst. Ner-*

) has, by his experiments, thrown much light on the cross
ns which give rise to paralysis and convulsions, yet he
ve gone too far in concluding that lesions on one side of
cannot give rise to convulsions on the same side of the
very remarkable that in the cases of lesion of one side
ollected by Burdach, convulsions occurred in twenty-five
ame side of the body as the disease; in only three cases
te side. Of these cases, those are, with reference to our
ially important in which there was paralysis on the op-
ith convulsions on the same side as the cerebral lesion. In
s of lesion of one corpus striatum, attended with paralysis
e side of the body, convulsions occurred on the same side
al disease in six instances, and in no instance on the op-
This appears to be very much in favour of the old opinion
nvulsions occur in cases of lesion of one side of the brain,
of the opposite side of the body, they most frequently
e side as that on which the cerebral lesion is seated.
decussation of the corpora pyramidalia of the medulla
me known, it could not fail to be perceived that the cross
brain upon the body were thereby explained. The oc-
paralysis on the opposite side of the body to the cerebral
ves that these decussating fasciculi themselves are the
edulla oblongata principally engaged in conducting the
e of the brain to the trunk; whilst the fact, that the other
cephalic portion of the cord do not decussate, affords an
those more rare cases in which lesions of the brain pro-
ts on the same side of the trunk.
ater difficulty in explaining the modes of action of the
ence on the cerebral nerves of the opposite or same side
For since these nerves arise, for the most part, above the
sation of the pyramidal bodies, the structure on which
of injuries of the brain on them depends must have
t; and, what involves the question in still more difficulty
the nerve of the same side is as frequently affected as
posite side in cases of cerebral lesion. For a detail of
fer to Burdach's work, in which an admirable industry
n twenty-eight cases of cerebral lesion of one side, the
opposite side of the face were paralysed; in ten cases,
me side. Paralysis of the eyelid was in six cases on the
ive, on the opposite. Paralysis of the muscles of the
ht cases on the same side; in four, on the opposite.
iris, in five cases on the same side; in five also on the
rdach, op. cit. iii. p. 372.) The tongue is generally
the paralysed side of the face.
ns in man as frequently cause paralysis of the retina of
hat of the opposite side. Since each optic nerve derives
n hemispheres, this is in some measure intelligible. But,
theory of the optic nerves, a lesion of one side of the
roduce not entire blindness of either retina, but merely
half of each, (see the account of single vision with the

two eyes in the 5th Book,) so as to cause blindness of the right or left side of the two eyes, which has, indeed, been observed as a temporary symptom. (See *Müller's Physiol. des Gesichtsinnes*, p. 93.) This, however, is not the ordinary effect of paralysis of one side of the brain; usually, either one eye or the other is entirely blinded. It is remarkable that in animals lesion of one side of the brain always causes blindness of the opposite eye; the difference of this result, from what takes place in the human subject, is explained by the structure of the commissure of the optic nerves in animals: nearly all the fibres of the two nerves decussate. This structure is necessary in them; since, from the direction of their eyes, the greater part of the field of vision of each embraces entirely different objects. Only the objects in the middle line throw their image on both retinæ; a small part only, therefore, of the retina of the one eye is identical in sensation with that of the other, and receives its fibres from the same side of the brain.

From the preceding facts, relative to the laws of action of the brain, and from those before detailed relative to the action of the spinal cord, we may form a classification of the different kinds of paralysis and convulsions, based on differences in the seat of the lesion which produced them.

1. *Paralyses.*—Paralysis may have its seat in individual nerves, and not in the brain and spinal cord; or it may be the result of disease in the latter parts. The local paralytic affections of nerves arise from any cause which destroys their power of propagating nervous action; as rheumatic affections, division, tumours, &c. The greatest number of paralytic affections, however, are dependent on lesion of the central organs, the brain, and spinal cord. In these cases, the paralysis affects either a vertical half of the body, hemiplegia, or a horizontal half, paraplegia. In the first form, the cause has its seat on one side of the brain and cord: in the second form, it is generally seated on both sides, but may be on one side only; for paraplegia is often produced when the disease implicates one side only of the brain.[?]

a. Paralysis from disease of the spinal cord.—In this class of cases, the seat of the disease is generally indicated by the extent of the parts paralysed. If merely the lower extremities and sphincters have lost their power, it is generally only the lowest portion of the cord that is affected; if the disease be seated at a higher point, a larger part of the body will be paralysed. If the disease affect the cord below the origin of the fourth cervical nerve, the paralysis will embrace the upper extremities, alone or together with all the parts below them, but not the phrenic nerve. If lesion affects the cord at a higher point than this, the phrenic nerve also is deprived of its power. Lesion of the medulla oblongata paralyses the cerebral nerves which arise from it, as well as the whole trunk. I am acquainted with a case of disease of the medulla oblongata from the pressure of a small tumour, in which imperfect paralysis gradually affected all the muscles of the body simultaneously; the upper and lower extremities, the tongue, eye, and face, were all partially paralysed. In the majority of cases of paralysis from disease of the spinal cord, the seat of the lesion is indicated by the extent to which the paralysis extends upwards. Injury to the lumbar portion of the cord constantly paralyses the lower, and never the upper extremities. If the arms be paralysed, the lesion must have its seat above the origin of the brachial nerves; but the lower limbs are in this case not necessarily affected. The effects of disease of the spinal cord are always seated on the same side as the lesion. If it be the sensibility of the limbs that is lost, the cause most probably, but not certainly, has its seat in the posterior columns of the cord; if it be motion which is lost, the anterior columns are more frequently, but not constantly, the seat of the lesion. Paralysis from disease of the spinal cord is sometimes complete, sometimes incomplete: when complete, the propagation of cerebral influence is wholly interrupted at some point; when incomplete, the influence of the will is still transmitted to the muscles, but the intensity of the motor power is lost; this is what is observed in atrophy of the spinal cord, or tabes dorsalis.

rom disease of the encephalon.—The paralytic affections of this class
nselves in any part of the trunk, in the face as well as in the upper
mities. Paralysis of the muscles of the leg, or of the sphincters,
e the result of disease either of the brain or of the spinal cord. It
to depend on disease in the brain, when other parts or functions are
re under the influence of cerebral nerves; as, for example, the muscles
functions of vision, and hearing, speech, or the movements of the
les of the face, &c. The paralysis may consist, likewise, either of
r of loss of sensibility, or of both. Paralysis of the motor power
esion of the corpora striata, the optic thalami, the investments of the
heres themselves, the corpora quadrigemina, the pons, the medulla
cerebellum. Serres, Bouillaud, and Pinel-Grand-Champ maintain
und paralysis of the upper extremities more frequently dependent on
halami optici; paralysis of the lower extremities, on disease of the
ut this is by no means well established. When it is the sensibility
is paralysed, the seat of the disease may be very various. Blindness
y caused by disease of the cerebral hemispheres, particularly of the
by disease of the corpora quadrigemina. Loss of common sensation
in disease of the medulla oblongata. Paralysis from disease within
ewise be complete or incomplete; the loss of motor power is most
lete when the lesion is seated in the corpora striata, optic thalami,
pons. Incomplete paralysis is most generally dependent on disease
misheres, or of the cerebellum. The paralysis is most apt to be
nvulsions or spasmodic contractions of muscles when the corpora
e medulla oblongata, or the parts at the base of the cerebrum, are the
se. Paralysis of the trunk is generally on the opposite side to the
c affections of the head as frequently on the same as on the opposite

—The cause of convulsions may be seated in the nerves themselves,
n the spinal cord.

e of the nerves.—Such are the convulsions caused by the reflection on
the spinal cord and brain, of an influence communicated to them,
l diseases of nerves as tumours, or neuralgic affections; from any
n on sensitive nerves; or, in children, from any local disease.

of the spinal cord.—These are regulated by the same laws as para-
om disease of the same part.

of the brain.—These also observe the same laws as paralysis from
It is, however, to be remarked, that lesions of the cerebral hemi-
bellum, and the pons Varolii, are more prone to cause paralysis;
rpora quadrigemina and medulla oblongata, to cause both paralysis

s investigated the laws of the propagation of nervous in-
brain and spinal cord, we have, in the last place, to con-
enomena resulting from disturbance of the equilibrium in
the brain. Division of certain parts of the encephalon

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character, and one calculated to be of great service in diagnosis, has been
M. Hall, as distinguishing paralytic affections dependent on disease of the
from those due to lesion of the nervous centres. He has found that when
either in experiments or by disease, from their connection with both spinal
, the muscles which they supply gradually lose their irritability; while, if
nd on lesion of the brain or spinal cord, so that the nerves, though no longer
, are still connected with a part of the central organs, the paralysed muscles
e their irritability, but are excited by galvanism to stronger contractions
ding sound muscles. Dr. Hall shows that in this way we may distinguish
of the face from cerebral disease and paralysis of the facial nerve; between
arm or leg and disease of the nerves of those limbs; between disease of the
dorsal region and disease of the cauda equina in the lumbar region, &c.
per in vol. xxii. of the Med. Chir. Trans. p. 316.)—*Translator.*

gives rise to phenomena which seem to indicate a disturbance in the equilibrium between forces opposed to each other in the two sides of the brain. These phenomena form a class of a quite peculiar character.

A certain part of the brain being divided, the action of the corresponding part of the other side becomes exaggerated. A vertical section of the pons Varolii on one side causes the animal to make a number of revolutions towards the same side; and this motion is arrested by dividing the pons on the other side. M. Hertwig confirms the result of M. Magendie's experiments, as to the rolling motion of the animal excited by division of the pons on one side; and states, moreover, that the eyes were turned from their ordinary position, one upwards, the other downwards. A transverse section of the pons being made, the dog could stand, but could not advance a step without falling; voluntary movements could still be performed, and sensation was perfect.

Division of the *crura cerebelli* (*processus ad pontem*) likewise in M. Magendie's experiments caused the animal to roll upon its axis towards the side on which the wound was inflicted; performing sometimes as many as sixty revolutions in a minute; and M. Magendie states that he has known them continue for a week without intermission.

After the removal of both corpora striata, the animals manifested an irresistible impulse to dart forwards, even when vision was lost.

Magendie has likewise observed that injuries of the cerebellum in Mammalia and birds cause a tendency to the performance of retrograde movements. He observed the same phenomenon after wounds had been inflicted on the medulla oblongata: pigeons, in which he had thrust a needle into that part of the encephalon, were observed by him for more than a month to walk backwards, never forwards; and he states that they actually flew backwards.

M. Magendie has observed, lastly, that certain kinds of injury to the medulla oblongata are followed by the animals moving in a circle, as on a riding course. He performed the experiment in a rabbit three or four months old; he exposed the fourth ventricle, raised the cerebellum, and then made a perpendicular section into the floor of the ventricle at the distance of $1\frac{1}{4}$ to $1\frac{4}{5}$ of a line from the mesial line: when the section was made on the right side, the animal turned towards the right; when on the left, it turned towards the left.

From the above important facts M. Magendie infers the existence in the brain of certain impulses by which the animal is necessitated to move in certain directions; by one forwards, by another backwards, by a third to the right, and by a fourth to the left: the detail of these movements he supposed to be directed by volition; and he imagines that in the normal state of the body the different impulses balance each other. Whether this explanation of the phenomena be the correct one, cannot in the present state of our knowledge be determined. It may easily be conceived that an animal might be impelled to such movements, if from the nature of the injury to the brain a certain motion of the nervous principle in one direction should take place in it, giving him the sensation of giddiness,—that is to say, of surrounding objects, or of his own body, moving round,—when he would endeavour to resist this apparent movement, or would follow it.

The phenomena last considered relate to the motor functions, but re are similar phenomena of the sensorial kind. Certain influences ing on the brain give rise, not to rotatory motions, but to sensations rotation. These are the revolving sensations of vertigo, of which are principally conscious by the sense of vision. It is a well-known that if any person turns round quickly upon his own axis for a rt time, he not only begins to lose his recollection, but also, when he ses to move, seems to see the objects around him still revolving in same direction. Purkinje has made some very curious observations tive to this phenomenon. It would appear from his experiments, t the direction which the revolution of the images shall take can be ulated by the position of the body, and particularly of the head while ning round, and by the position of it afterwards when we have ceased nove round. It is only when the experimenter has kept his head he ordinary vertical position while turning round, that afterwards, en he stands still with his head upright, the objects appear to revolve he horizontal direction. If while turning he holds his head with the iput upwards, and then raises it when he stands still, the apparent tion is like that of a wheel placed vertically revolving around its axis. d thus, according to the difference in the position of the head when ning and when standing still afterwards, the direction of the apparent olving motion can be altered. If, however, the body lying upon a is made to revolve with this disk, an apparent motion of objects in gents is perceived. It results from a repetition of these experiments t the apparent motion produced, when the rotation of the body has sed, and the position of the head is changed, always seems to take ce in the plane perpendicular to that axis of the head, regarded as a ere, around which the real motion was performed. From this rerkable result Purkinje infers that turning of the head and whole ly gives to the particles of the brain the same tendencies to particular tions as the particles of a revolving disk receive, and that this disbance of their state of rest is manifested by the apparent movements ertigo. We might perhaps better explain the phenomenon by suping it to result from the impressions of the blood in a particular ction on the cerebral substance. It is possible, however, that the olving motion of the body may cause an aberration of a more subtile ciple than the particles of the cerebral substance or blood,—in fact, aberration of the nervous principle itself, such as affects the senium so as to produce the apparent motions of objects. It is certain t narcotic substances give rise to the vertiginous sensations of the tions of objects, although they produce no mechanical disturbance of brain. But in whatever manner they be explained, these sensorial nomena afford a very interesting parallel to the revolving motions of body, caused by a disturbance of the equilibrium of nervous actions notor parts of the brain.

BOOK V.

OF MOTION; OF VOICE AND SPEECH.

SECTION I.

OF THE ORGANS, PHENOMENA, AND CAUSE OF MOTION IN ANIMALS.

CHAPTER I.

Of the different kinds of Motion and Motor Organs.

THE vital motions of the solid parts of animals present two principal kinds, differing in the organs of their production. in their phenomena, and in their causes: they are, the motion from contraction of fibres, and the oscillatory motion of cilia with free extremities, in which no other organic apparatus of motion can be distinctly demonstrated. The first kind of motion is produced by the shortening of fibres, which either have a longitudinal direction and are fixed at both extremities, or form circular bands; the contraction or shortening of the fibres bringing the fixed parts nearer to each other. This kind of motion is generally effected by means of muscular fibres; in some few instances it is produced by fibres which differ from the muscular in structure and chemical properties. The second kind of motion consists in the vibration, in a determinate direction, of microscopic cilia with which the surfaces of certain membranes are beset. Here only the base of the motor organ is attached. By the motion of the contractile fibres, and especially by muscular motion, solid parts of the body are approximated to each other, or fluids are impelled onwards in muscular tubes. By the motion of cilia, fluids and minute microscopic particles of solid matter are merely made to move over the surface of membranes; the fluids do not here fill the entire cavity of the tubes, nor do the membranes themselves contract. The motion due to contractile fibres prevails much more extensively through the body than the ciliary motion.

The muscular fibrous structure is distributed in three strata, the arrangement of which is connected with the earliest process of organisation. All the systems of the body are developed from the laminæ of the germinal membrane, which originally covers the yolk in the form of a disk; this membrane is formed of three layers, the external or serous, the internal or mucous, and the middle or vascular layer: and when the embryonic portion has become separated from the rest of the germinal membrane by a constriction corresponding to the future umbilicus, the parts of the body endowed with animal or voluntary ion are developed in the external layer; those endowed with organic nvoluntary motion in the internal layer; and in the middle or vas-r layer is formed the heart, together with all the parts belonging to vascular system, which, at a later period, ramify in the structures eloped in the external and internal laminæ. The portion of the y formed in the external layer of the germinal membrane separates the different structures of the animal nervous system, the osseous em, the system of voluntary muscles, and the skin. The portion of body developed from the mucous layer separates into the different ctures of organic life, namely, the fibrous structures forming the sup-t of the different organs, such as the fibrous tunic of the intestinal e, (the tunica nervea of the older anatomists,) the serous membranes, mucous membranes, the muscular coat lying between the fibrous the serous, and, lastly, the organic nervous system. (*Von Baer, twickelungs-geschichte. Scholien.*) This organic portion of the body udes the intestinal tube, the urinary and the generative apparatus, of which have in nearly their whole extent an organic muscular r, which is the sole cause of all the motions they exhibit. The per pharyngeal muscles and the perinæal muscles, which are en-red with voluntary motion, and belong to the animal portion of the y developed in the external lamina, are not here included. Even efferent ducts of the accessory glands of the organic system have a cular coat continued on them from the muscular layer of the great s; for, though the muscular coat of these ducts has not, it is true, their delicacy, been demonstrated so plainly as the other mem-es, yet its presence is certain: the *ductus communis choledochus*, ureters, and the *vasa deferentia* have been seen to contract, both taneously and under the application of stimuli. That the efferent ts and their glands are originally developed from the walls of the s into which they open is an ascertained fact, at least, with regard e glandular apparatus of the intestinal tube.

he muscles of animal life are distinguished from the pale muscular s of the organs of the organic portion of the body, which are not ect to volition, not merely by their moving under the influence of tion, by their red colour, and their solidity, but even by the great rence of their microscopic character. We see that the primitive cular fasciculi of the animal system present, under the microscope, sverse markings, and that the primitive fibres of these muscles have lar varicose enlargements following each other in close succession; le the fasciculi of the muscular coats of the intestines, urinary blad-and uterus are destitute of those cross markings, and their primitive ls uniform, not varicose, threads. In the œsophagus the two sys-s border closely on each other; the muscles of the pharynx belong e animal system, those of the œsophagus to the organic; but the fourth of the proper œsophagus receives an investment from a um of muscular fasciculi, descending on it in an arched form to a ed limit, in which Schwann has discovered the transverse mark-and the fibrils of varicose structure; these, however, belong to the yngeal muscular apparatus: no such fasciculi are met with on the of the œsophagus. But according to M. Ficinus (*De Fibræ Mus-*

ng life: in disease this power of resisting imbibition is frequently
and after death it always ceases. Our ideas concerning the increased
ty of tissues and astringent substances, as far as they are founded on
rvations, presuppose a variability in the power of opposing the per-
tion of fluids, which, according to physical laws, must ensue.

he second primary kind of motion in animals, that of vibrating cilia,
served on certain membranes both in the animal and in the organic
ion of the body; and it is in some measure probable that it exists,
ast in some of the lower animals, in the vascular system also,
ely, in the interior of the vessels. It is seen in many of the lower
als in the animal part of the body, namely, over the entire surface.
e higher animals it is seen on the surface of the body during the
ryo state only, as in the embryo of the frog; and, in some animals,
e larva state, as in the tadpole; but it has been discovered by Pur-
to exist in the parietes of the ventricles of the brain, both in the
ryonic and adult state of mammalia. In the organic portions of the
the mucous membranes (not all of them) present it, even in the
est animals, up to man himself. It is possible that the motion of
itive fluids which is observed in the lower animals where there is
eart and no distinctly contracting vessels, is, in all cases, merely
ffect of the motion of cilia; and the circular motion of the sap in
ells of many plants may be produced in a similar way. The
omena of this kind have been described at pages 48 and 166; they
ot in any way tend to confirm the idea of a spontaneous motion of
s.

CHAPTER II.

OF CILIARY MOTION.*

phenomena of ciliary motion were observed in the Mollusca by De Heide,
venhoek, Baker, Swammerdam, and Baster, although the mode of their pro-
n was not explained until a much later period. The cilia on the surface of
fusory animalcules were distinguished by Leeuwenhoek, who described their
n and use. They were afterwards observed by Baker. De Heide and Leeu-
ek noticed the currents on the surface of the branchiæ of Mussels; Swammer-
Leeuwenhoek, and Baster observed the whirling motion of the embryo of
sca in the ovum. The former phenomenon has recently been minutely described
Erman and Dr. Sharpey, the latter by Carus.

first observations relative to the existence of ciliary motion in vertebrate ani-
were made by Steinbuch, who remarked the currents in the water around the
iæ of the Batrachia, but he did not recognise their cause, and sought in vain for
Gruithuisen discovered the phenomenon on the tail of the larva of the frog;
r. Sharpey described the existence of the currents not only around the branchiæ,
er the whole surface of the body of the tadpole; similar observations with re-

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e principal writings on ciliary motion are those of Purkinje and Valentin, in Müller's
. i. p 391, ii. 159; their work, De Phænomeno generali et fundamentali motus vibra-
ntinui in membranis, &c. Vratisl. 1835, 4; and a paper in the Nova Acta Nat. Cur. t.
Sharpey, in Edinb. Med. and Surg. Journ. vol. xxxiv. July, 1830; Edinb. New Phil.
vol. xix. July, 1835; and Cyclopedia of Anat. and Phys. Art. Cilia; Grant, Edinb. New
Journ. 1826; Edinburgh Journal of Science, 1827.

spect to the branchiæ were made by Huschke, Raspail, and myself. It remained, however, for Purkinje and Valentin* to make the important discovery, not only that the phenomenon in question was in the Batrachia, as in the invertebrata, dependent on the oscillation of cilia, but that it exists, from the same cause, on the surface of the mucous membranes of birds, reptiles, mammalia, and man. It appeared to be absent in fishes; it exists, however, in them also. I will now give an account of the most important facts relating to this subject, with some remarks upon them.

a. Of the different parts of animals in which the ciliary motion exists.

The ciliary motion has in different animals been observed on the external surface, in the alimentary canal, in the respiratory system, in the generative organs, in the cavities of the nervous system, and on the surface of serous membranes.

1. *The external surface* presents the ciliary motion in the Infusoria, in the coralline Polypifera (the Bryozoa, in contradistinction to the Anthozoa,† of Ehrenberg); in the Actiniæ and Asterias also, according to Dr. Sharpey; in the Echinus, according to Ehrenberg; in the Acalepha; in the Mussel (on the mantle); in the Gasteropoda (snails); terrestrial and aquatic (over the whole surface); in the Turbellaria of Ehrenberg, and in the Spermatozoa. In the higher animals the ciliary motion is not observed on the external surface, except in the embryo, and in the very young larvæ of amphibia. During the earliest period of the larva state, the whole superficies of the body was seen by Dr. Sharpey, and by Valentin and Purkinje, to present the ciliary motion; afterwards, the extent to which the phenomenon is observed, becomes gradually less, until it is confined to the root of the tail and the sides of the head; and when the extremities have become developed it has wholly disappeared.

2. *Alimentary canal.*—Purkinje and Valentin have discovered the ciliary motion in the alimentary tube of reptiles; but only at its upper part, namely, on the internal surface of the mouth, the Eustachian tube, the pharynx, and, in the chelonia (turtles and tortoises,) and serpents, in the œsophagus also. In mammalia and birds the ciliary motion does not exist either in the cavity of the mouth, or in the pharynx and œsophagus.

3. *Respiratory organs.*—The mucous membrane of the larynx, trachea, and bronchi, has been found by Purkinje and Valentin to present the ciliary motions in all the air-breathing vertebrata. In mammalia and birds the phenomenon commences at the glottis, not existing in the cavity of the mouth and pharynx in these classes. In birds it extends into the air-sacs which communicate with the lungs. The external branchiæ of the larvæ of the amphibia present the ciliary motion; but on the internal branchiæ, which these larvæ have in the second stage of their developement, and on the branchiæ of fishes, the phenomenon is, as Dr. Sharpey observed, absent.

4. *Nasal cavity.*—In this situation the ciliary motion is constantly present. It was discovered there by Purkinje and Valentin. In reptiles and amphibia, birds and mammalia, it occupies both the external and internal wall of the nasal cavity; and in mammalia the observers just named have detected it also on the mucous membrane of the sinuses opening into the nostrils, the frontal and maxillary sinuses, and in the Eustachian tube. In the rabbit the lining membrane of the lachrymal canal and sac presents no ciliary motion, though the phenomenon exists in the nasal cavity; the ciliary motion is also not present on the conjunctiva.

5. *Generative organs.*—In vertebrate animals the ciliary motion has been found by Purkinje and Valentin to occupy the mucous surfaces of the female generative organs only. It is observed in the oviducts, the uterus and vagina of mammalia (not in young animals); and it persists even during pregnancy on those parts of the uterus which are not occupied by the chorion.

The male organs do not present any ciliary motion in vertebrate animals, and it has een observed in any organs of the invertebrata, which indubitably belong to the sexual apparatus.

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* Müller's Archiv. 1834; and afterwards in their work, De Phænomeno, &c.

† M. Ehrenberg (Symbolæ Physicæ, and Müller's Archiv. 1834, p. 578,) divided the polypi into two groups, the Bryozoa and the Anthozoa. The Bryozoa are those which have a perfect intestinal canal, with a ciliated surface (whence they are called ciliobrachiata by Dr. A. Farre, Philos. Transact. 1837). The Anthozoa have merely a digestive sac with one opening, and their surface is destitute of cilia. M. Ehrenberg has since made a further division of these Anthozoa. A similar arrangement of the Polypifera, showing the coincidence of a complete intestinal canal, with the presence of cilia on their surface, was given by Dr. Sharpey in his article, "Cilia," in the Cyclop. of Anat.

Urinary apparatus.—In the vertebrata the ciliary motion is entirely wanting in rinary organs. But Purkinje and Valentin have detected it in the saccus calcareus ails, an organ which opens upon the surface of the body near the anal aperture, which, from containing uric acid, may be regarded as the kidney of these animals. le also has seen the ciliary motion in this organ.

The ventricles of the brain.—The ciliary motion has been discovered on the lining brane of the ventricles of the brain by Purkinje, who has with M. Valentin ex- ed it in this situation in man, many mammalia, birds, amphibia, and fishes. It ds through all the ventricles of the brain, and all the cavities of the brain and l cord in the fœtus and embryo.*

The serous membranes (the pericardium and peritoneum in the frog) have been l by Mayer† to present the phenomenon, and the observation has been confirmed I. Valentin.‡

om the review which we have thus taken of the parts which present the ciliary n, it is evident that it is a phenomenon which exists very generally in the animal lom; but that the extent to which it prevails in the different classes of animals is various. In no class of animals except the crustacea?§ is it entirely wanting.

e vibrations of cilia are also the cause of the motions of the embryos of many als in the ovum, and of the motion of the free ova (or, more correctly, embryos,) veral of the lower animals, as the Radiata and Polypifera.

b. Of the phenomena of ciliary motion.

equires a high magnifying power to perceive the ciliary motion in most animals. e it, a very small piece of any mucous membrane on which it exists should be ened with water and covered with a plate of glass, by which it is spread out, and rder rendered clearly visible. With the aid of a powerful microscope the phe- non of the ciliary motion may then be seen. First, there is the appearance of an lation, and the small bodies floating in the water are seen near the border of the rane to be driven along in a determinate direction. With a still higher magni- power, the cilia themselves may sometimes be recognised, although seldom very ctly, on account of the great rapidity of the motion. Often the effect of the of the innumerable moving organs is so great, that it is necessary to be quick king the observation, lest the entire portion of the membrane should escape from eld of vision. The influence of the ciliary motion on the fluids and small bodies are in contact with the ciliated membranes may also be very well shown by ing on the surface a fine powder. The motion of the cilia is so active on the hiæ of the larva of the salamander, or of the mussel, that small portions of those s, when placed in water, are regularly whirled round.

motion of the cilia, having a uniform direction, gives rise to currents over the e of the mucous membranes. The direction of these currents on most parts has already determined by the labours of Dr. Sharpey, and of Purkinje and Valentin. irection of the current in the trachea of a hen was found by Purkinje and Va- to be from without inwards; in the oviduct it was from within outwards: the sition, therefore, that the semen is conveyed to the ovum by ciliary motion, is pable of proof. On the inferior turbinated bone of a rabbit the current was as- ed by Dr. Sharpey to be directed from behind forwards; in the antrum it red to be directed towards the opening of the cavity. In the cavity of the mouth batrachian amphibia the current produced by the ciliary motion is, both on the nd roof of the cavity, directed towards the œsophagus. At the palatal entrance nostril, in a lizard, the current on the inner side of the opening carried small les of powder into it; on the outer side it carried them out into the mouth.

c. Of the organs which produce the ciliary motion.

organs of the ciliary motion are, according to Purkinje and Valentin, delicate

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üller's Archiv. 1836, 289, and Valentin's Repert. 1837, Bd. i. p. 156.

upplemente zur Lehre vom Kreislaufe, Pt. ii. p. 7. Froriep's Notiz. No. 1024.

epertorium, Bd. i. p. 149.

e Dr. Sharpey's article, "Cilia," in the Cyclop. of Anat. vol. i.

onclusive as to the independence of the ciliary motion from the nervous system
hose in which the poisonous substances were applied directly to the vibrating
e; for in frogs killed by narcotics the muscles and nerves retain their suscepti-
of the influence of stimuli locally applied for a long period, while both nerves
uscles to which narcotics are directly applied soon lose their irritability. The
lone is an exception to this rule; it continues to beat for a long time after solu-
f opium or of the extract of nux vomica has been applied to its external surface,
immediately paralysed when the same poison is applied to its internal surface.
do not regard the minuteness of the vibrating organs in comparison with the
ive fibres of the nerves as any argument against their phenomena being depen-
n the nervous system; for the muscular fibrils themselves are so much more
than the nervous fibres, the latter fibres are distributed in such small number
muscles, and the mass of muscular substance which is seen by means of the
cope to intervene between the nervous fibres is so great, that the existence
influence exerted at a distance is a necessary supposition in accounting for
tion of the nervous fibres on muscles. Moreover, there are parts in which,
not in the muscles, a much more minute ramification of the nervous fibres
to take place. The persistence of the ciliary motion, however, after the
application of narcotic poisons, sufficiently proves the peculiarity of this
nenon, and its independence of any immediate influence of the nervous system.
ally important fact in relation to this question is, the existence of the ciliary
on the surface of the so-named ova of polypiferous animals, which are how-
e animated, though undeveloped embryos. The extreme conditions of the
nenon afford here the most interesting subject of comparison: the lowest condi-
that of the ciliary motion on the undeveloped embryos of polypi; the most
that of the motion of the rotatory organs of the wheel animalcules. In the
instance we have the phenomenon taking place on membranes devoid of special
re, and allied to this condition is that of the vibratory motion of cilia on the
membranes of the higher animals, which is not arrested by the action of
ine and other narcotic poisons; the motion of the cilia of the rotatory organs,
contrary, is effected distinctly by muscular action, and is subject to the will;
ertainly dependent on the nervous system: strychnine also, as Ehrenberg has
arrests this form of ciliary motion.

e present state of our knowledge, thus much may be advanced:—
hat the ciliary motion of the mucous membranes is due to the action of some
m contractile tissue;
hich lies either in the substance of the cilia or at their base;
hat this tissue resembles in its contractility the muscular and other contractile
of animals;
hat its properties in so far agree with those of the muscular tissue, at all events
t of that of the involuntary muscles of the heart; and with the vibrating laminæ
ower crustacea, that the motions which it produces continue without ceasing
equable rhythm;
at its properties agree also with those of a muscular tissue of the heart, in its
continuing long after the separation of the part from the rest of the animal

at this tissue differs essentially, however, from muscle, in the circumstance of
ons not being arrested by the local application of narcotics;
at the ciliary motion presents itself under conditions where it is not probable
omplicated organisation exists, namely, in the undeveloped embryos of polypi-
nimals.

ircumstance of the ciliary motions not being immediately dependent on the
e of nerves, constitutes a point of resemblance between them and the oscilla-
tions of certain plants, for example, the Oscillatoria. How far this comparison
ct must be determined by further research. But however this may be, there
exists in the mucous membranes that present the ciliary motion, an active
ich regulates the mode of action of these microscopic organs, since the cilia
frequently observed to act simultaneously in regular series. There is here a
e influence of which extends beyond individual cilia; for though the simul-
action of a series of cilia producing waves might be explained by supposing
lia to be attached to one contractile band, yet there is also frequently observed

a certain remission and acceleration of the ciliary motion over considerable tracts of a vibrating membrane, which must have a more general cause. I have sometimes seen a total rest of the cilia for a considerable interval over a large extent of the surface of the branchiæ of an annelide allied to the genus Sabella, which I brought with me in sea-water from Copenhagen, this state of rest being again succeeded by a state of activity. Analogous phenomena are frequently enough observed in the vegetable kingdom; they are not necessarily therefore to be referred to a variation in the nervous influence.

The explanation of the production of currents by the ciliary motion is also attended with difficulty. The mere vibration of cilia from one side to another cannot give any particular direction to a fluid. The motion of the cilia, too, in a conical space, which, according to the observation of Purkinje and Valentin, is the most frequent kind of motion, can merely give rise to the motion of the fluid in a circle around the cilium. For the cilia to give rise to a current of the fluid in a certain direction, it is necessary that they should strike and bend in one direction; such, indeed, was the motion which Purkinje and Valentin observed sometimes, and that which I saw in most cases. But even with this motion it is necessary, in order to produce a current, that the cilia in returning to their erect position should present a smaller surface to the fluid than they do in making the stroke. According to the observation of MM. Purkinje and Valentin, (*Nov. Act.* lxvii. pt. ii.) it is the return of the cilia from their bent to the erect state which gives the impulse to the water, and produces the current.

CHAPTER III.

OF THE MUSCULAR AND ANALOGOUS MOTIONS.

I. *Of the contractile tissues.*

If we leave out of consideration the enigmatical tissue which is the cause of the ciliary motion, four forms of contractile tissue may be distinguished; namely, the contractile tissue of vegetables, the contractile tissue of animals which yields gelatin by boiling, the arterial contractile tissue, and the muscular tissue.

a. Of the contractile vegetable tissue.—The most remarkable of the phenomena of irritability presented by plants have been already described at page 45.

The cause which influences the motion of the plants so as to induce the expansion of the leaves and rising of the petiole is the augmentation of light during the day; the light favours the ascent of the sap, and thus must produce turgescence of the cellular portion of the motor intumescence. Each portion of the cellular cylinder in the mimosa has a tendency to curve towards the centre or axis of the petiole; but the lower part is the thickest, and hence the tendency will there be strongest, and will, when the intumescence is rendered turgid by the influence of light, cause the elevation of the petiole. If, however, the lower half of the intumescence be removed, the tendency of the upper half, being no longer counterbalanced, will come into play, and depress the petiole: if the upper half only is removed, the lower will act with increased force, and raise the petiole still more, as in the experiment already mentioned.

The fibrous tissue has the property of curving when submitted to the action of atmospheric air or oxygen ("*par oxigenation.*")

The depression of the petiole, and the folding of the leaves of the osa and other plants when irritated mechanically, or by heat or s, is, according to M. Dutrochet, also the result of the same action he fibrous tissue, which becomes oxygenated whenever the plant is ted in any way, it being a fundamental theory with this physiolo- that excitation is in all cases merely oxidation of the living tissue, nal or vegetable.

o excite the motion of the leaflets and petiole of the mimosa, it is necessary that either the intumescence itself, or even the leaves, ld be touched. The stimulus may be applied to a more or less dis- part. Even the roots transmit the excitation to the leaves; M. rochet moistened a small portion of the roots of the mimosa with huric acid, and, before there was time for absorption of the acid to taken place, the leaves became folded. M. Dutrochet has satisfied self that the transmission of the excitation is effected by the woody of the plant, not by the cortical or medullary parts; for these he d might be entirely removed, and irritation above or below the spot ld still be propagated beyond it. The excitation extends gradually the points to which the stimulus is applied; first the nearest leaves, then the most distant, becoming folded. The excitability is greatly enced by light and temperature, as well as by the presence or ab- e of atmospheric air. Both the excitability and mobility of the osa are lost after a few days, when the plant is deprived of light; usceptibility of external stimulus being lost before the movements leep and waking cease. Variations in the temperature of the at- here also cause the quickness of the transmission of the excitation one part of the plant to others to vary, and at 47½° Fahr. no mo- can be excited.

Of the contractile tissue of animals which yields gelatin by boil- —The first traces of vital contractility in animals are presented by a e so similar in the structure of its fibres, as well as in its chemical erties, to cellular tissue, that it might almost lead us to regard them entical, and to ascribe to cellular tissue not merely the property of icity which it retains after death, but also an organic contractile er. Until more is known of the tissue in question, we designate it contractile tissue yielding gelatin, by which we sufficiently distin- it from the fibrinous muscular tissue.

addition to their transparency and smoothness, the fibres of the lar tissue, which have been already described, have a very peculiar acter in their wavy disposition. When not artificially extended, are never straight, but have an arched or waving direction. The s of each primitive fasciculus are, however, always parallel; it is asciculi which are thus waving. This character of the cellular tis- s owing to its great elasticity. If the fasciculi be extended and ghtened, they return, as soon as the extension is remitted, to their nal curved state. A chemical examination of cellular tissue, after freed by washing from blood or lymph, shows that it belongs to the of tissues that are converted by boiling into gelatin; and its fibres n this circumstance, again distinguished from muscular fibre which gs to the albuminous tissues. This is important, as affording a s of distinguishing the contractile cellular tissue from those muscular fibres which have not the varicose structure; for example, the muscular fibres of the uterus. The latter fibres, however, differ from the fibres of cellular tissue by another character, namely, by the want of the curved and waving position of their fasciculi.

The contractile property of the tissue allied to cellular membrane has been long known; but it has, in many parts of the body, been frequently confounded with muscular action; and, on the other hand, in consequence of the slight change of diameter produced by this kind of contraction, the phenomenon has by some been quite neglected, or even denied to exist. To verify the existence of the phenomenon in question, it is best to study it first in those parts in which it is presented in the most marked degree, and in which the tissue can be submitted to an accurate microscopic and chemical analysis. The tunica dartos has a very active contractile property, which is most frequently excited by cold.

The primitive fibres of the fasciculi which compose this tunic are excessively delicate and elastic. When examined with the compound microscope, they are seen to be uniform cylindrical filaments, with a serpentine waving disposition. Their diameter, as determined by M. Jordan, varied from $\frac{1}{3000}$ to $\frac{1}{1111}$, and in the mean was $\frac{1}{1430}$ of an English line. The fibres of cellular tissue had the same diameter. On the other hand, the fibres of the dartos differ in diameter from the muscular fibres. The varicose muscular fibres are smaller, the muscular fibres of the colon, which are not varicose, are larger, and those of the iris are much more minute. But, independently of their size, the fibres of the dartos exactly resemble the fibres of cellular tissue in their serpentine disposition and elasticity, and are by these characters distinguished from ordinary muscular fibres.

On the other hand, traces of contractility are displayed in true cellular tissue in other parts of the body; for example, in the subcutaneous cellular tissue between the folds of the prepuce, which frequently in irritable individuals contracts very strongly in the cold bath. The phenomenon of "*cutis anserina*," seems to be one of an analogous nature. The sudden erection of the nipple is probably produced in the same way; for I have good grounds for questioning the correctness of the common opinion, that the latter phenomenon is the result of vascular turgescence, or true vascular "erection." In the first place, the nipple does not contain any of the spongy tissue which forms the *corpora cavernosa penis;* those anastomosing veins and sinuses, and the arteriæ helicinæ projecting into the venous sinuses, which characterise the true erectile tissues. Secondly, the erection of the nipple is perceptible not only in females when it is handled during the existence of the sexual excitement, but also in men, quite independently of sexual feeling. Thirdly, the nipple in man becomes erected almost instantaneously and quite visibly when it is suddenly and roughly handled in one's own person; the same takes place in a less degree also when the nipple is exposed to the contact of cold water, and in a more marked degree when the individual suddenly enters a cold bath. Fourthly, the erection of the nipple is not attended with any increased fulness; on the contrary, while it is becoming erect, which occupies a few seconds only, it

mes narrower, and loses in breadth what it gains in length. Now,
l these circumstances there is great similarity to the phenomena of
levation of the cutaneous follicles in "*cutis anserina*," and to those
e contraction and wrinkling of the prepuce in cold water. The
ion of the nipple is, therefore, most probably the effect of contrac-
of the subcutaneous cellular tissue which surrounds it. It is re-
able that the contractile cellular tissue exists principally beneath
those parts of the skin which have a dark tint, as, for example,
kin of the penis, the scrotum, and nipple. If, in addition to what
ave already stated, it be recollected that the skin in its whole ex-
independently of any cutaneous muscle, manifests a certain degree
ntractility,—a phenomenon which cannot be owing to the admix-
of muscular fibres in its tissue,—it will appear very probable that
e parts which we have mentioned,—the scrotum, skin of the penis
nipple,—owe their contractility to a contractile cellular tissue,
h, in the structure of its primitive fibres, does not differ from ordi-
cellular tissue. The similarity of the chemical properties of the
s, and its difference in chemical composition from muscular fibre,
gthen this opinion; for M. Jordan has shown that the dartos is
lly converted into gelatin by three hours' boiling; and that its
on in acetic acid, like that of cellular membrane and all tissues
h yield gelatin, is not precipitated, nor rendered turbid by ferro-
de of potassium. (*Müller's Archiv.* 1834.)

Jordan has likewise instituted some experiments relative to the
e of the contractile property of the dartos. The stimulus which
usually excites its contraction is cold; warmth relaxes it; and gal-
m does not affect it: which fact is the more interesting, as it affords
ans of distinguishing the contractility of cellular tissue from that
scular fibre. The dartos has no share in producing the retraction
e testis towards the abdominal ring; this is effected solely by the
aster. The mode in which the shortening of the fibres of the con-
le tissues, which we have been considering, is effected, is probably
inflexion into waving lines by the reciprocal attraction of aliquot
of the fibres.

Of the elastic and contractile tissue of arteries.—It has been
dy shown, at page 212, from the results of galvanic experiments
ll as from the real properties of the elastic coat of arteries, that
ssue does not possess muscular contractility. But as I have already
bed the properties and function of this tissue, I need not return to
e.

f the muscular tissue. 1. *Chemical properties of muscle.*—In respect of its chemi-
perties, it has been already shown that muscle belongs to the class of animal
which cannot be made to yield gelatin by boiling, and of which the solution
ic acid is precipitated by the red ferrocyanide of potassium: all the gelatin ex-
from muscle by boiling is due to the cellular tissue which unites the muscular
li. By these chemical characters muscular fibre may be easily distinguished
e different elastic tissues, including the elastic tissue of arteries, which yield
in boiling, and of which the solution in acetic acid is not precipitated by ferro-
e of potassium: whereas it is difficult and often impossible to distinguish chemi-
hether a body which belongs to the class of albuminous substances is muscle

Uncoagulated albumen may, it is true, be recognised by its solubility in cold
kewarm water, and by its property of being coagulated by a temperature of from

158° to 167° Fahr., by alcohol, and by metallic salts; uncoagulated fibrin may be known by its spontaneous coagulation when removed from the animal body; uncoagulated casein by its solubility in boiling as well as in cold water: but coagulated albumen and the coagulated fibrin of the blood and muscles cannot be distinguished from each other further than that fibrin decomposes the peroxide of hydrogen, while albumen has not that property. There is no chemical means of distinguishing the fibrin of the blood from that of muscle.

The red colour of muscle has been ascribed to the presence of cruorin, the colouring matter of the blood; and the colour of muscle is, like that of the blood, rendered brighter by exposure to the air. But Dr. Schwann has once observed the naturally pale muscles of the carp become of a dark red during maceration for a short time in the cold in winter; a fact which seems opposed to the idea of the colouring matter of muscle and that of the blood being identical.

2. *Structure of muscle.*—The elementary parts of muscles are either beaded or cylindrical fibres, which are unbranched, and are arranged parallel to each other in fasciculi. According to Professor Krause, they are united together in the primitive fasciculi by a transparent tenacious fluid. The diameter of the primitive fasciculi, which contain from five to eight hundred fibres, is stated by Professor Krause, to be from $\frac{1}{140}$ to $\frac{1}{19}$ of an English line. The diameter of fasciculi taken from the pharynx of the human subject was found by Dr. Schwann to be from $\frac{1}{47}$ to $\frac{1}{40}$ of an English line. The primitive fasciculi are invested and connected together by cellular tissue, so as to form larger secondary fasciculi, which are again connected together by cellular membrane. Anatomists differ very much in their accounts of the form of the primitive fibrils. Some, as Professor Schultze, describe them to be simple, uniform filaments; others, as Bauer, Home, Milne Edwards, Prevost and Dumas, and Professor Krause, regard them as composed of globules; while others, again, describe them to be beaded threads. The first and last of these descriptions, though apparently contradictory, are both correct, these two forms existing in different kinds of muscle.

1. *Muscles whose primitive fibres have a varicose or beaded structure, and whose primitive fasciculi have cross markings.* It is this class of muscles that has been the most examined. It includes those muscles of voluntary as well as involuntary motion which are remarkable for their red colour; all the voluntary muscles, namely, except the expulsor muscle of the urinary bladder; and, among the involuntary muscles, the heart. All red muscles, however, are not of this kind; thus, the red muscular substance of the gizzard of the bird belongs, together with the muscular coat of the whole intestinal canal, to the second class of muscles.

The transverse striæ of the primitive fasciculi, seen when a portion of these muscles is examined with the microscope, follow each other very closely, are always quite parallel, and generally pass in a straight line across the fasciculus; occasionally, but rarely, they are a little curved. On the primitive fasciculi of the heart the transverse striæ are much less distinctly visible, but nevertheless exist, as Professor R. Wagner correctly remarks.

Dr. Schwann has applied himself during an entire winter to the microscopic examination of muscle; the following are the results at which he has arrived. The diameter of the primitive fasciculi varies from $\frac{1}{48}$ to $\frac{1}{40}$ of an English line. The fibres are most easily examined in the muscles of the rabbit. They are beaded filaments, presenting under the microscope a succession of dark points from $\frac{1}{1666}$ to $\frac{1}{1250}$ of an English line in breadth, separated by bright and somewhat narrower portions of the filament.

The beaded muscular fibres with primitive fasciculi marked with transverse striæ are not confined to vertebrate animals. The voluntary muscles of insects, for example, are wholly constituted by them. Each primitive fasciculus has a very delicate sheath, which can often be perceived forming a transparent border to the fasciculus.

Professor R. Wagner (*Müller's Archiv.* 1835, p. 318,) has examined the structure of the muscles in many of the lower animals. He met with muscles of which the primitive fasciculi presented cross striæ, in insects, crustacea, cirropoda, and arachnida.

2. *Muscles with uniformly cylindrical primitive fibres and primitive fasciculi devoid of transverse striæ.* These fibres are found to compose the muscular coat of the whole intestinal canal of the higher animals from the œsophagus to the anus.

This is the more remarkable, as the muscles of the pharynx belong to the former ı,—the muscles with beaded fibres. The diameter of the primitive muscular from the large intestine of the human subject was found by Dr. Schwann to be 07, 0.0011, and 0.0013; in the mean, about $\frac{1}{1000}$ of an English line. Their border ıtline was quite smooth and even.

2. "Of the vital properties of muscle."

n addition to the vital properties common to all animal tissues, mus- possess sensibility and contractility. The sensibility of muscles is ed in the sensitive nervous fibres distributed to them, and not in muscular fibrils themselves: contractility is the essential property of cles, which manifest it under the influence of every stimulus; while er organs, not muscular, are by the same stimuli excited to the mani- ation of other properties, such as sensation, secretion, &c. Muscles sess but slight sensibility to external impressions, as of cuts and punc- s. A needle passed through the skin may be carried deeply into substance of a muscle without pain being produced; the heart laid has been observed to possess a very slight degree of sensibility. muscles, however, are endowed with a very delicate sense of their rnal condition; or rather, their nerves communicate accurately to sensorium a knowledge of the states induced in them by their con- tion: by virtue of this property we are not only made conscious of sensations of fatigue and cramp in muscles, but acquire through cular action a knowledge of the distance of bodies and their rela- to each other, and are also enabled to estimate and compare their ght and resistance. This muscular sense cannot, however, be seated e same nervous fibrils which excite the motions.

Iuscles are thrown into action by any stimulus applied to them- es or to their motor nerves. All stimuli, as mechanical or chemical ıences, cold, heat, or electricity, produce the same effect. They all ite contraction of the muscles even when applied to their nerves. ds act more readily when applied to the muscles themselves than n applied to the nerves; it is not, however, as we have before re- ked, a constant rule that acids excite no muscular contractions, n they act on the nerves alone. Dr. Bischoff and Professor Win hmann have at all events frequently seen muscular contraction luced in the latter case. The property which muscles possess of racting under the influence of any stimulus was made the subject pecial study by Haller, (*Deux Mémoires sur les parties sensibles et tables*, Lausanne, 1756,) who called it "irritability," in contra nction to the sensibility of nerves. "There are, however, so many othetical notions and false ideas connected with the name "irrita- y" in this sense, that it figures better in the history of medicine than iscussions on physiology itself."

'he contractility of muscles is preserved for a longer time by cold- ded than by warm-blooded vertebrata. The contractility of the t is retained for several hours in fishes, reptiles, and amphibia; and e frog the other muscles also retain their contractility for several rs, particularly in the colder season of the year: a tortoise for a week r decapitation presents some contractility in its muscles. In higher nals the muscular contractility is seldom retained more than one or hours after death; there are instances, however, in which it is not lost for many hours, an example of which is afforded by the cutaneous muscle of the hedgehog. Nysten, (*Rech. de Physiol. et de Chim. Path.* 321,) in his experiments on the bodies of executed criminals who were previously in good health, found that the different muscles lost their contractile property in the following order: the left ventricle of the heart first, the intestinal canal at the end of forty-five or fifty-five minutes, the urinary bladder nearly at the same time, the right ventricle of the heart after the lapse of an hour, the œsophagus at the expiration of one hour and a half, the iris fifteen minutes later, the muscles of animal life still later, and last of all the auricles of the heart; the right auricle being the part which retained its contractility longest, in one instance contracting under the influence of galvanism sixteen hours and a half after death.

There are many substances which have the property of deadening the muscular irritability. The muscle of animals killed by immersion in carbonic acid gas, hydrogen, carbonic oxide, or by the vapours of sulphur, contract very feebly, or not at all, when stimulated; while in the atmosphere, or oxygen, muscles retain their contractility much longer. (*Tiedemann's Physiol.* i. p. 551.—*Nysten*, loc. cit. p. 328.) The action of pure water on muscles for any length of time diminishes their irritability in a remarkable degree. This was first observed by Nasse, and has been recently confirmed by Dr. Stannius. The legs of frogs freed from the skin and laid for a short time in water, are no longer adapted for delicate experiments on the excitability of nerves and muscles. (*Hecker's Annal.* Dec. 1832.) Narcotic substances, applied directly to the muscles, destroy their irritability; applied to the nerves, they deprive the nerve, at the point which they have acted on, of the property of exciting muscles to contraction; but, between that point and the muscle, the motor power of the nerve is preserved. When animals are killed by the introduction of narcotic poisons into the blood, the irritability is not affected in so great a degree as by the local application of the narcotic in a concentrated state; muscular contractions can be excited by irritating the muscles or nerves for several hours after death in frogs poisoned by narcotics. Substances which have a decomposing chemical action on animal matters,—the caustic alkalies, concentrated acids, and chlorine, for example,—annihilate the irritability of muscles instantaneously at the point which they touch. There are no bodies known to have the property of heightening the irritability of muscles.

Muscular contractility is subject to the general laws of animal excitability. Muscles become feeble if seldom excited to action; and a great exertion of their contractile power always induces temporary exhaustion of it. Excitement and rest are, therefore, equally necessary for the maintenance and increase of the muscular power.

The state of contraction of muscles, which renders them firmer and harder, is alone the active condition; in their more elongated state they are relaxed. There is no fact to justify the supposition that muscles possess a power of active expansion. The opinion that the heart has such a power has been refuted by Oesterreicher (see p. 185). The living muscles must not, however, be supposed to be at any time in a

of complete relaxation. They are constantly, even in the state of
subject to the influence of the nervous principle; this is seen in
retraction of divided muscles, in the slight tremors of muscles laid
during life, and in the distortion of the features, and drawing of
tongue to one side, in hemiplegia.

a muscle is observed at the moment of its contraction, it is seen
ecome thicker in the same proportion as it is shortened: and very
n its fasciculi are seen to be for an instant bent into waving lines.
circumstance of the muscles becoming firmer in the state of con-
tion might naturally induce the conjecture that their substance be-
es condensed so as to occupy a smaller volume; although, without
being the case, the mere strength of the attraction of certain parts
e muscle towards each other would explain the increased firmness.
he condensation of the muscular substance during its contraction is
oo slight to aid us in explaining the phenomena of muscular con-
ion. And it is possible that the condensation which took place in
e experiments was owing to the air contained in the divided vessels
g pressed out of them by their contraction; it might certainly be thus
pletely accounted for. When the experiment of M. Ermann, of sub-
ng the hinder half of an eel immersed in a glass jar, to a galvanic
ery, is repeated, the portion of eel should be prepared under water,
introduced into the tube without coming into contact with the air.
he modes in which the muscles could become shorter during their
raction are threefold. 1. The zigzag inflexion of the muscular
culi. This can be seen with the naked eye in muscles during con-
ion, but may be more accurately observed with the aid of a lens.
fasciculi of muscular fibres are thrown into zigzag inflexions. MM.
rost and Dumas (*Journ. de Physiol.* iii. p. 311,) have, in particular,
ied this phenomenon.

M. Lauth has made some important observations with regard
uscular contraction. (*L'Institut, No.* 57, 70, 73, 1834.—*Müller's*
iv. 1835, p. 4.) Exposing a muscle, which still preserved its irri-
ity, to the action of galvanism under the microscope, he perceived
its contraction was effected in two ways. When the muscle con-
ed most forcibly, its whole secondary fibre or primitive fasciculus
thrown into angular inflexions; a more feeble galvanic stimulus
ed a shortening of the entire secondary fibre, without any zigzag
xion. In the latter case, the surface of the secondary fibres, or
itive fasciculi, is not smooth, but presents, in its whole extent,
verse rugæ (rides), which are also visible in the fibres while bent
zigzag lines, but are quite independent of that zigzag inflexion.
sciculus of fibres can, it is plain, become shorter in two ways; either
e whole fasciculus being bent alternately in opposite directions, the
s in the intervals of the flexure remaining parallel to each other,
h mode of shortening takes place visibly in the larger muscular
culi, or by the fibres of the fasciculus spreading out in the intervals
nsverse lines which divide the fasciculus into aliquot parts. The
r mode of contraction, very probably, takes place, together with
irst, in the muscles of insects, and perhaps also in those of the
er animals.

3. It is possible that the muscular fibres of the second class (those of the organic parts of the body) contract both in the first and the second mode simultaneously; but there is a third manner in which the muscular fibres of the animal system may shorten themselves,—namely, by the approximation of the bead-like enlargements, and the contraction of the interspaces between these enlargements of the primitive fibres. Such a mode of contraction can neither be demonstrated, nor proved not to take place. The absence of the beaded enlargements in an entire class of muscles would render any theory of muscular contraction defective, which was based on them alone. Still, the approximation of the globules of the primitive fibre may very possibly take place in the muscles of animal life, in addition to the other modes of contraction which are seen in the primitive and secondary fasciculi; and there are, in fact, some reasons for believing that in them it actually does occur.

The rigidity of muscles after death, rigor mortis.—This phenomenon is due to a particular state of the muscles, which ensues at a certain period after death, giving rise to stiffness of the limbs, and after a time ceases. The rigidity affects the neck and lower jaw first, according to M. Sommer; next, the upper extremities, extending from above downwards; and lastly, reaches the lower limbs: in some instances it begins in the lower extremities, or affects them simultaneously with the upper extremities. Out of two hundred cases, M. Sommer only observed one in which the rigidity did not commence in the neck.

The rigidity, according to Sommer, never commences earlier than ten minutes, and never later than seven hours, after death. Both Nysten and Sommer state that its duration is greater in proportion to the lateness of its accession. If the muscular energy was undiminished at the period of death, as in men killed by asphyxia, the rigidity of the limbs ensues later and continues longer; while, on the contrary, in bodies of persons who have died of acute diseases attended with great depression of the vital powers, it comes on more rapidly; after death from typhus, for example, M. Sommer has sometimes known it to be developed in fifteen or twenty minutes. In the bodies of individuals exhausted by chronic diseases, the same fact is observed. After sudden death from acute diseases, the rigid state of the limbs continues for a long time, even though it be rapidly developed. Hunter and Himly have remarked that, in the bodies of persons killed by lightning, no rigidity of the muscles takes place; M. Sommer, however, states that, in a dog killed by an electric shock, the phenomenon ensued at the ordinary period after death. The remark of Orfila, also, that after death from the vapour of charcoal the limbs do not become rigid till after a longer period than usual, was found by M. Sommer to be incorrect: he remarks that, if in some cases the rigidity of the limbs appears to be late in being developed, this is owing not so much to the mode of death, as to a state of apparent death preceding the real cessation of life. The assertion that the muscles do not become rigid after poisoning with narcotic substances, is also contradicted by the experiments both of Nysten and Sommer on animals. Nysten had made the remark that the rigidity is equally intense in muscles paralysed by hemiplegia: this is confirmed by Sommer, with the proviso that the paralysis must not have been attended with any considerable modification of nutrition, nor with serous effusion into the muscles; for, in such a case, Sommer has once observed an entire absence of rigidity on the paralysed side. Nysten remarked that death from tetanus was attended with or quickly followed by a cessation of the spasms, and that the body then remained in a flexible state for some hours before the rigidity of the corpse ensued: in one case observed by Sommer, however, the tetanic cramp of the muscles of the jaw passed immediately into the rigidity of death. In new-born infants and old people, the rigidity of the limbs generally comes on earlier, is less intense, and lasts a shorter time. Sommer observed that, contrary to the statement of Nysten, the body in many instances became rigid before it was com-ly cold, and sometimes even while still warm. The body becomes rigid after r in water as well as in the air; but in water of the temperature of 32° to 66° . the rigidity is greater and of longer duration than in air of the same tempera-

With reference to the question of the influence of the brain and spinal cord on production of the phenomenon which we are considering, Sommer confirms en's observations as to the fact that destruction of the central organs of the us system in animals has no influence on the development, degree, or duration e subsequent rigidity of the body.

e cause of the rigidity is, according to Nysten, seated in the muscles; for the still remain stiff, though the fasciæ and even the lateral ligaments of the joints vided, but become flexible as soon as the muscles are cut through. This state- is confirmed by Sommer, who adds that, although the limb recovers its mobility the division of the muscles, still the divided muscles themselves remain firm igid,—a fact previously noticed by Rudolphi. Nysten referred the rigidity of bodies to the organic contractility of the muscular fibres. Orfila, Beclard, and iranns believed the phenomenon to be dependent on the coagulation of the blood. M. Sommer thinks this opinion incorrect, since the body sometimes becomes very when the blood has not coagulated, or but imperfectly; thus, in persons drowned, igidity of the limbs is very great, while the blood is often fluid; and the same case in men and animals killed by prussic acid. Should it at a future time be mined that the rigidity of the corpse is owing to a physical contractile property e muscular fibres exerted at the time of the loss of their vitality, and ceasing their decomposition, the phenomenon would be more analogous to the physical action of the fibrinous coagulum to a smaller and denser substance.

CHAPTER IV.

OF THE CAUSES OF MOTION IN ANIMALS.

an inquiry into the causes on which the motions of the solid tex- s of organic bodies depend, it is necessary in the first place to dis- uish between the motions of parts devoid of nerves, and those which consequent on a reciprocal action exerted between the contractile e and the nervous system. Motions of the first kind are presented lants, and perhaps also by some parts of animals which are not cular.

he time has not arrived for inquiring into the causes of the ciliary ion. We do not even know by what mechanism it is produced. In reat independence of the influence of the nervous system it resem- the motions of plants. The motions of cellular tissue, or the con- ile animal tissue which yields gelatin,—motions which are readily luced by the action of stimuli, particularly cold, heat, and mechani- influences, on the tissue itself,—in some degree resemble those of ts and the cilia, which are independent of the influence of the ous system. They resemble the motions of plants in another cir- stance also, namely, in not being perceptibly excited by electricity. motions of the cellular and allied contractile tissues are not, how- , entirely withdrawn from the influence of the nerves. The con- ion of the skin and dartos is excited not only by external stimuli, frequently also by causes seated in the nervous system.

he contractile property of the muscles is intimately dependent wo different influences,—the influence of the blood, and that of the es.

1. *Influence of the blood.*—Stenson first pointed out that muscles lose their power of motion when the current of blood (that is, of arterial blood) towards them is obstructed. This phenomenon is sometimes observed when a ligature is applied to a large arterial trunk in the human subject; the power of moving the muscles under the influence of the will is either partially or wholly lost, until the collateral circulation is developed. This fact has been confirmed by Arnemann, Bichât, and Emmert. (*Treviranus, Biologie*, v. p. 281.) Segalas (*Journ. de Physiol.* 1824,) also has observed that, when the abdominal aorta is tied in animals, the hind-legs are rendered so weak, that after eight or ten minutes they can scarcely be dragged along. Whether the principal influence of the blood consist in its maintaining the contractility of the muscles, or in its enabling the nerves to convey the influence of the will, has not been investigated. It is certain that the arterial blood undergoes in the motor organs a change, which, while it gives the blood the venous character, renders it unfit to maintain in the muscles their contractile property,—in other words, that the property of contractility requires for its perfect preservation the constant action of arterial blood on the muscular fibre. This is confirmed by the phenomena observed in the subjects of the cœrulean disease; in whom, on account either of a patent state of the foramen ovale, or ductus arteriosus, or a narrow condition of the pulmonary artery, the arterial and the venous blood are mixed, or the process of arterialisation imperfectly performed. Such persons are incapable of any great muscular exertion.

2. *Influence of the nerves upon the contractility of muscles.*—The question of the action of the nerves in exciting the muscles to contraction must not be confounded with that of their influence in the maintenance of the muscular contractility. Haller regarded the contractility of muscles as a vital property peculiar to them, and independent of the nerves; he named it "irritability." This great physiologist, whose theory was adopted by Fontana, Soemmering, Nysten, Bichât, and others, taught that all stimuli acting on muscles excite their contractility without necessarily exerting their influence primarily on the nerves, and through them upon the muscles; and that the nervous stimulus is in fact merely one kind of the many stimuli by which the contractility of the muscular fibre may be excited. The proofs which Haller and his followers adduced in support of this theory have long lost their weight. The heart does not, as they supposed, act independently of all nervous influence, and its nerves are not insensible to external stimuli. The heart is, with reference to nervous influence, in the same condition as all other parts supplied by the sympathetic nerve. Not only can it be excited to contraction by galvanism, as has been observed by Von Humboldt, Pfaff, Fowler, Wedemeyer, and myself; but Humboldt and Burdach have succeeded in influencing its mode of action by irritating the cardiac nerves (see pages 200 and 526.) The influence of the nerves on organic muscles can be demonstrated very distinctly also, as my experiments show, by irritating the cœliac ganglion, which causes the peristaltic motions of the intestines to become much accelerated. My own researches, and those of Wutzer, Retzius, and Mayer, have moreover sufficiently refuted Scarpa's opinion that the sympathetic

has no connection with the anterior motor root of the spinal
s and the motor cerebral nerves. These facts, however, merely
is to conclude that the nerves of the heart as well as the nerves of
muscles, transmit motor influence; they still leave undecided the
ion, whether in the sound body, and in a heart removed from the
, the cardiac nerves are necessary for the maintenance of the con-
le power of the organ.

correctness of Haller's theory has been disputed by other physiologists,—as
, Monro, Prochaska, Legallois, and Reil,—who contended that the motor power
ls on a reciprocal action exerted between the nerves and muscles. Were such
se, the contractility of muscles would differ essentially from that of plants,
is excited directly by external stimuli, without the aid of nervous influence.
port of this opinion it is urged, that stimuli applied to the nerves excite the
s to action; that narcotic substances, which seem to have a special action on
vous system, when applied to the muscles, destroy their contractility; and that
tion of the brain and spinal cord also has the effect of diminishing the contrac-
wer of the muscles. It must, however, be confessed that these arguments are
means weighty. The duration of the muscular irritability is not less after the
tion of the brain and spinal cord, than after death from other causes; and
ng with narcotic substances merely causes the influence of the brain and spinal
be no longer transmitted to the muscles. The irritability of the nerves and
s is far from being destroyed in frogs by narcotic poisoning: I have seen the
henomena produced by the application of stimuli to the nerves or muscles for
long time in frogs thus poisoned. Treviranus has adopted a middle course
gard to this question; and in accordance with what is observed in plants, which
eir irritability to the influence of light, but yet are excitable by other stimuli,
s that the influence of the nerves is a necessary condition for muscular irritabi-
it that all stimuli do not act by their intervention on the muscles. Tiedemann
ologie, i. p. 547.—Translation by Gully and Lane, p. 295,) agrees with Haller
rding the muscular contractility as a peculiar property inherent in the muscles
lves, but believes the maintenance of this property in them to be dependent on
n and nervous influence; and further holds that the nerves do not merely con-
e stimulus which excites the muscular contraction, but afford an essential con-
or the manifestation of the vital property of the muscles. This essential influ-
the nerves may consist either in their imparting to the muscles their property
g affected by stimuli, in other words, of manifesting irritability; or it may be,
imuli, even when applied to the muscles, must act first upon the nerves, and
their medium excite the contraction of the muscular fibre. It is evident, from
going remarks of Tiedemann, that there are here involved two perfectly distinct
ns: 1. Is the influence of the nerves necessary for the preservation of the vital
y of the muscles by virtue of which they contract, and is this property lost
e nervous influence is cut off? 2. Are the nerves conductors, through the
of which all stimuli act upon the muscles? does even the apparently direct
n of the muscles themselves act first on the nervous fibrils distributed in the
ar substance, and only through the medium of them affect the contractile tissue?
t question may be decided in the affirmative, without the second proposition
ecessarily admitted; but if the second receive an affirmative answer, the admis-
the first is a necessary consequence.

the integrity of the nerves necessary for the preservation of the vital contrac-
muscles? Nysten had observed, that, a short time after an apoplectic seizure,
cles paralysed in consequence of the cerebral lesion still contracted under the
e of galvanism; and Wilson Philip, on the authority of Sir B. Brodie, asserted
erve, whose communication with the brain and spinal cord was cut off, retained
nsiderable time, its faculty of exciting the muscles to contraction when irri-
(*Phil. Transact.* 1833, pt. i. p. 62.) I had reasons for suspecting that the per-
of this excitability of a divided nerve, when its continuity had not been re-
y regeneration, is not without its limits; and several experiments instituted
ference to this question by myself, in conjunction with Dr. Sticker, (see page
ve proved that, when the communication with the central organs of the nervous

system is completely interrupted, not only the power of the nerves to excite muscular contractions, but with it the irritability of the muscles themselves, also, is gradually lost.

2. Are the nerves the sole conductors, through the medium of which all stimuli necessarily act on the muscles? The reasons for admitting such to be the case are the following:

a. The stimuli which excite the contractions of muscles, when applied directly to their tissue, are the same that produce the like effect when applied to the nerves. I have, it is true, frequently observed a difference in the action of stimuli on nerves and muscles; the mineral acids and alcohol namely, which, when applied immediately to the muscles, cause them to contract, had not the same effect when applied to the nerves. This difference does not, however, appear to be constant; for M. Humboldt has produced a tremor of the muscles by the application of alcohol, chloric acid, arsenic, and even of the metallic salts to the nerves; and Dr. Bischoff and Professor C. Windischmann have, I learn by private communication, in some instances seen muscular contractions produced in frogs by the application of mineral acids to the nerves.

b. The substances which destroy the contractility of muscles are also destructive of the excitability of nerves; for, although narcotic substances taken into the circulation, and destroying life by their action on the brain and spinal cord, do not immediately annul the excitability of the nerves and muscles of the body,—the muscles and nerves of frogs thus killed retaining their excitability for a long period,—yet the immediate application of these substances to the nerves and muscles destroys locally the muscular contractility and nervous excitability. Nerves immersed for a short time in a solution of opium lose their susceptibility of stimuli to the extent in which the fluid has acted on them; while between this part and the muscle they retain their property of exciting muscular contractions under the influence of stimuli. Muscle also immersed in solution of opium loses its vital properties to the extent to which the contact with the poison has reached. This similarity of action of narcotics on nerves and muscles renders it probable, that the effect of such substances in making muscles to which they are applied insensible to the influence of stimuli, is owing to their destroying the excitability of the nervous filaments distributed in the muscular substance.

Although the conclusion just stated seems to be proved by the arguments which we have adduced, yet it is evident that the contractility must be a property of the muscles themselves, and that the nerves cannot even during life impart to them a power which they do not themselves possess. But the manifestation of the contractile property of muscles presupposes a concurrent action of the nerves; the discharge of an imponderable agent by the nerves is indeed as necessary for causing certain portions or minute elementary parts of the muscular fibres to be attracted towards each other, as this attraction of the parts of the fibre towards each other is essential for the shortening of the whole fibre. The modes of contraction of the fibres under the influence of nervous energy have been considered and illustrated by facts in the preceding chapter. The strength of the attraction between the angles of the inflected fibres may be best estimated from the power which the living muscles possess of resisting in their contracted state the greatest extending force; while after death, when this power of reciprocal attraction in their particles is lost, they are very easily lacerated and torn asunder.*

Of the mode of action of the nerves on the muscles in exciting their contractions we are at present quite ignorant. MM. Prevost and Dumas (*Magendie's Journ. de Physiol.* t. iii.) have described the nerves to be so distributed in the muscles that at each of the angles of the muscular fasciculi formed by their zigzag inflexion in the act of contraction, that is to say, at each of the points towards which other parts of the muscular fasciculus are attracted, or which attract each other, there is a nervous fibre running transversely across.

The observation of MM. Prevost and Dumas, that the nervous fibres form loops running transversely across the muscular fasciculi at the points of their angular inflexion, serves as the basis for their theory of muscular motion, according to which these transverse nervous loops are supposed to attract each other, and thus to shorten the muscular fibre.

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* Compare the observations of Tiedemann, Physiol. p. 553.—Translation, p. 299.

however, we reflect that the whole hypothesis of the similarity of the electric ie nervous principles is unsupported by any facts, and that, as we have shown ges 513 and 514, these principles differ essentially as to their conductors and in- rs, the theory of Prevost and Dumas, and any other modified theory of muscular n as due to electric action, will be perceived to be baseless.

s muscular fibres certainly appear to become shortened during contraction in the als of the nervous loops which cross the fasciculi; it is probable, therefore, that rts of the muscle which are traversed by the nervous loops, and which are prin- y exposed to the nervous influence, attract each other, and thus give rise to the r inflexion of the muscular fasciculi.

Schwann is engaged in performing some experiments with the view of ascertain- hether the contractile force of a muscle diminishes or increases as the contraction muscle is greater. He employs, in these experiments, the musc. gastrocnemius og with a peculiar apparatus.

oncluding this discussion on muscular contractility, it appears necessary to direct on to the fact that any sudden change in the condition of the nerves of muscles, atever cause it be produced, is productive of a shock to the muscles. The closing rruption of the galvanic circle, sudden destruction of the nervous tissue, burning, cal influence, mechanical stretching, and all such influences, appear to give an se to the imponderable principle of the nerves, by which either a current or oscil- of that principle towards the muscle is excited, whether the external influence en or depress the vital energy of the nerves themselves. Hence muscular con- ns may attend any, even the most feeble state of the vital forces, the nervous ple being capable of such motion or oscillation as excites the muscles to action, any change is produced in the state of the nerves, even though the activity of rvous principle is upon the point of being annihilated. We have here an opportunity of verifying the law laid down in the Prolegomena, that excitation is perfectly nt from augmentation of the vital forces,—that an animal system may be stimu- o death, and that even the narcotic substances (the alterantia nervina), which hs property of producing so great a change in the nervous matter, give rise to oms of irritation or excitation, while they destroy the vital properties of the l.

SECTION II.

OF THE DIFFERENT MUSCULAR MOVEMENTS.

CHAPTER I.

Of the involuntary and the voluntary movements.

e most obvious distinction which presents itself in classifying the ent muscular movements, is that between the involuntary and the tary. On closer examination, however, this division is found to s natural than it at first appears. It does not agree with the dif- ces in the forms of the muscular tissue; and there are many in- tary movements performed by muscles which are subject to the -movements in some cases following as regular a rhythm as do the ns of the heart. Certain muscles also, which are quite independ- the influence of the will, are nevertheless influenced by particular of the mind; and lastly, the fact that the nerves have as great an nce over the involuntary as over the voluntary movements, de- s such a classification of much of its interest. The facts stated in a ding page were sufficient to show that a division of muscular movements into the voluntary and involuntary would not find any support in the anatomical structure of the muscular tissue; for, although the muscles of the organic parts of the system are distinguished by the absence of transverse striæ on the primitive fasciculi, and by the uniform non-beaded character of their fibres, while they act also independently of the will, yet the urinary bladder, which in respect to structure belongs to the organic muscles, is capable of some degree of voluntary motion. The fasciculi of the fibres of the iris again have not the cross striæ, and nevertheless a voluntary influence can be exerted indirectly upon the iris by turning the eye inward (see pages 535 and 593). On the other hand, though the muscles of the animal parts of the system are characterised by the transverse markings of the primitive fasciculi, and the beaded form of their fibres, at the same time that they are subject to the will, yet the heart here constitutes an exception, it being referable by the structure of its fibres to the animal muscles, but with respect to its involuntary motion to the organic. There is no correspondence also between the colour of the muscles and their division into involuntary and voluntary. The voluntary muscles are generally red; but those of fishes are, for the most part, white. The muscles not subject to volition, as the muscular coat of the intestines, are generally of a pale colour; but the muscular gizzard of birds and the heart are composed of muscle of a deep red colour; while the muscular coat of the bladder, which is in some measure under the influence of the will, is as pale as that of the intestines. This difference of colour is certainly not merely owing to the greater or less abundance of blood-vessels, and of the red colouring matter of the blood. The peculiarity appears to reside in the muscular substance itself, which agrees with the cruorin of the blood in being rendered of a brighter red by the action of the atmosphere. The division of the muscular movements into the voluntary and involuntary finds, it is true, better support in the difference of the nerves supplying the different muscles; but even in this point of view it is subject to exceptions, the urinary bladder and iris, though supplied by the sympathetic, being capable of some voluntary motion.

If, indeed, we reflect that many muscles, which are ordinarily under the influence of the will, are nevertheless constantly being thrown into contractions in opposition to the will, as is the case, for example, with the sphincter ani; that some muscles belonging to the animal system are incapable of being made to act voluntarily, except in very few individuals, of which we have examples in the cremaster, &c.; and lastly, that all the voluntary muscles are also frequently excited to involuntary action, whether in consequence of "nervous reflection," or "associate nervous action," or by mere mental conceptions,—as in laughing, yawning, or sighing, and still more frequently by passions of the mind, —it will be seen that we have reasons sufficient for adopting a classification in which the internal causes of the different motions are more kept in view. Since the class of involuntary motions is founded on a negative character, some physiologists have more aptly divided the animal movements into the voluntary and automatic. The involuntary motions are, however, with reference to their causes, of such various kinds, that this division also appears to me to be objectionable; for what

itutes the difference between the automatic rhythmic movements of
eart and respiratory muscles, and the movements from reflex ner-
action? The different causes of the muscular motions seem to be
kept in the following classes.

Movements excited by heterogeneous stimuli, external or in-
l.—By heterogeneous stimuli I understand here all other causes
uscular contractions than the mere impulse of the nervous
iple itself. There are but very few instances in which such
li give rise to muscular actions in the normal state of the body;
is the case, however, for example, with the stimulus of the bile and
, which excite the movements of the intestines; with the stimulus
urine causing the bladder to contract, &c. For the production of
ular motion, a change in the state of the nerve supplying the
e is necessary. It is indifferent whether this change in the nerve
ected through the medium of its anatomical connections with the
l organs, or from its own blood-vessels, or whether the influence
produces it be derived entirely from without. All muscles, ani-
s well as organic, are equally capable of being excited to motion
is manner; but the movements thus produced are always in-
tary, whether the muscle be ordinarily withdrawn from the in-
e of the will or not. The point at which the stimulus may act is
fold.

It may act on the muscle itself.—In this case, the nervous fibrils
buted in the muscle are primarily affected, and through their in-
e the muscular fibre is made to contract. The direct application
external stimulus causes the heart, the intestinal canal, the urinary
ler, and all the involuntary as well as the voluntary muscles, to
act.

On the nerve.—The application of a stimulus to the nerve before
reached the muscle has the same effect as irritating it in the
le itself.

On the central organs of the nervous system.—Irritation of the
and spinal cord always gives rise to contractions in the muscles
derive their nerves from the irritated part of the nervous centres.
nfluence of the brain and spinal marrow on the movements of
supplied with cerebro-spinal nerves has been considered at pages
nd 633; and the influence of the same parts on organs the nerves
hich belong to the sympathetic system, at page 565. The ex-
ents of Dr. Wilson Philip tend to show that every part of the
and spinal cord can exert an influence on the motions of the
; while, in the case of the muscles supplied by cerebro-spinal
s, particular parts of the brain and spinal cord are always con-
d with particular muscles.

important difference is found to exist in the action of irritating
s. Many stimuli,—as mechanical irritants, heat, electricity, the
es, and other substances,—excite muscular contractions when ap-
directly either to the muscles themselves, to the nerves, or to the
l organs of the nervous system. Other substances, on the con-
, excite no contraction of the muscles, unless when they act on the
l organs of the nervous system through the medium of the circu-

lation: thus the local application of narcotics to a muscle or nerve destroys their irritability or excitability at the part acted on, but gives rise to no muscular contractions; while the same substances produce the most violent convulsions, when, mixed with the blood, they exert their influence on the brain and spinal cord. That in animals poisoned by narcotics the convulsions are due to the irritation of the great nervous centres, is evident from the fact that division of a nerve puts a stop to the tetanic convulsions in the part which it supplies. (See page 609.)

2. *Automatic movements.*—By automatic movements it is intended here to designate all those muscular actions which are not dependent on the mind, and which are either persistent or take place periodically with a regular rhythm, and are dependent on normal natural causes seated in the nerves or the central organs of the nervous system. The cause of the rhythmic movements may be either in the sympathetic nerve or the great nervous centres, but never in mere cerebro-spinal nerves.

a. Of the automatic movements dependent on the sympathetic.—These movements are presented, 1, by muscles of which the primitive fasciculi are marked by transverse striæ,—namely, by the heart; and 2, by muscles of which the fasciculi have no transverse markings,—as the intestinal canal, uterus, and urinary bladder.

The automatic movements of the heart, like those of the animal muscles of the body, are contractions of momentary duration succeeding each other quickly. The automatic motions of the muscles of the second series are more gradual and more enduring, and their intervals of rest are much longer. Whether this difference be owing to the different structure of the muscle, or to the nature of the nervous influence, is not known. The fact that the bladder, although it may be made to contract voluntarily, yet it is not capable of a rapid contraction, is in favour of the kind of motion being due to a peculiarity of the muscular tissue. The action of the urinary bladder being, when the viscus is distended, periodically increased in force, is so far referable to the automatic movements, but otherwise does not belong to them.

In all the automatic movements of the viscera of organic life, without exception, there is observed a certain order of succession in the contractions; one part of the viscus contracts before another, and the motion thus traverses the organ in a determinate direction during each period of the rhythm. The contractions even of the uterus of animals is vermicular; at least they are so, as I have witnessed, in the rat when excited by irritants locally applied. The periodic contractions of the uterus are generally observed to occur only during parturition; they in rare instances take place during pregnancy, but are then more feeble. Irritation of organs presenting the automatic movements has also an influence on the rapidity and force of the contractions; stimuli, whether external or internal, acting on the heart, cause it to beat quicker and more forcibly. In acute diseases of great intensity, which makes such an impression on the central organs of the nervous system as to give rise to fever, the heart not only acts more frequently than natural, but even the mode of contraction of its fibres is altered, causing hardness of the pulse; hence in fever, while the powers of the system are unimpaired, the pulse is hard, strong, and quick. In proportion as the powers of the system decline, the impression of the disease on the central organs continuing, the beat of the heart, though it retains its altered character, becomes feeble; and the pulse accordingly, still hard, also becomes weak, while it increases in frequency. A hard, full, and frequent pulse, therefore, is in acute disease an indication that a violent impression is made on the nervous centres, the vital powers not being essentially impaired; while, in proportion as the pulse, still hard, becomes more feeble and frequent, we know that the vital powers are sinking. The pulse becomes slower in many affections which are not inflammatory, but are attended with interruption of the func-

of the central organs of the nervous system,—such as syncope and apoplexy.
otions of the intestinal canal are rendered both more energetic and quicker by
al irritation, as when the intestine is exposed to the air; or by internal irritation
mucous membrane, as in diarrhœa: irritation of the spinal cord also is productive
smodic automatic movements of the intestinal canal and uterus. The same in-
of the automatic movements is produced by irritation of the sympathetic nerve;
at least, is the effect of irritation of the cœliac ganglion, by the application of
s potash, on the intestines of the rabbit.

y of the organs which present the automatic movements are provided with
ters. While the automatic contractions of these muscular tubes or sacs become
ically stronger, the sphincters, as for example the sphincter vesicæ or os uteri,
for a time constantly closed; but their resistance is at last overcome, and they
ated by the contents of the viscera, which are thus driven against them with
sing force. The antagonism which subsists between the sphincters and the
lar coats of the viscera is evidently not so much due to any cause seated in the
es themselves, as to the mode of action of the nerves in them.

primary cause of the rhythmic contractions of the organic muscles is connected
he mode of action of the sympathetic nerve on the muscles: it is not seated in
ain or spinal cord. This constitutes an essential distinction between the auto-
movements of the organic and those of the animal muscles. The rhythmic con-
ns of the heart continue even when it is removed from its connections in the
This continued action of the organ is not due to the stimulus of blood, for it is
p with the same regularity when the heart is emptied of all its blood. The
of the heart continues also in vacuo; it cannot, therefore, be owing to the stimu-
the air. The intestinal canal likewise still presents its peristaltic motions when
ed from the body; and the separated oviduct of a turtle has been seen to contract
o expel the ova.

inquiry as to the cause of muscular contractility leads to the conclusion that a
rent action of the nerves is always necessary for the act of muscular contrac-
and hence, as well as from the fact that the stimuli applied to the cœliac gan-
produce a change of some duration in the peristaltic movements of the intestine,
st infer that the organic nerves distributed in the muscular substance have a
al share in the production of these automatic movements, and that the rhythmic
ctions of these organic muscles are not independent of the nerves, as Haller
ed.

s been proved that the automatic motions of the organic muscles, like all mus-
notion, depend primarily on the influence of the nervous principle; that the cause
rhythm of these automatic motions is connected, not with the nature of the
lar fibres, but with the peculiarity of the nervous system of the organic mus-
and that the cœliac ganglion has the property of exciting, when irritated, the
ltic motions of the intestines. It appears, moreover, that the sympathetic nerve
its ganglionic structure even in its more minute ramifications; and the power
intestine to perform its peristaltic motions is found to be preserved even when
parated from the mesentery. From these facts, then, I conclude that even the
branches of the sympathetic which ramify in the intestinal coats have the same
of causing periodic contractions as the cœliac ganglion was proved to possess.
planation that applies to the peristaltic movements of the intestines has the
orce with relation to the rhythmic motion of the heart; the first observed motion
heart in its simple tubular condition is indeed of a peristaltic nature. Since,
re, not merely the larger ganglions of the sympathetic, but even its ultimate
ations in the tissues of organs, seem to possess the power of giving rise to
ic motions, we can understand how the rhythmic movements of the heart, intes-
nd oviduct of the turtle are enabled to continue when these organs are removed
heir connections in the body.

othetical explanation of periodic movements.—The sympathetic nerves may be
red to imperfect conductors, whether the insulating influence be seated in the
a or in the nervous fibres themselves. This being granted, the cause of the
ic action, or periodically increased action of the nervous principle on the mus-
ibre, is obvious. The ganglionic parts of the sympathetic nerve will, as imper-
nductors, tend to arrest the current of the nervous fluid. The general current,
other hand, following the peripheral distribution of the nerve, strives to reach

up to the time of death. The theory of M. Kind, that it is the stimulus of the
ting on the cutaneous nerves, and transmitted to the spinal cord, which gives
to respiration as a reflected movement, is not very probable; for a frog wholly
ved of its skin continues to respire as before; and a frog with its head only in the
ill breathe equally well, whether the skin of its body be immersed in water or
unded with air. If the stimulus of water acting on the skin were sufficient to ex-
he respiratory movements, the fœtus of mammalia ought to perform them in the
s. It is evident, therefore, that the cause of the first respiration of the infant, as
as of the continued respiratory movements, must be some influence which could
st in the fœtal state, but which comes into operation immediately after birth; and
nfluence is not the stimulus of atmospheric air either in the lungs or on the skin.
ause of the first respiration can only be the impression made on the medulla
gata by the arterial blood, which is formed in consequence of the first entrance
e air into the respiratory organs, and in less than a minute reaches the primum
ns of the respiratory movements in the central organs of the nervous system.
rterial blood is also very beautifully shown to be the cause of the continuance of
spiratory movements throughout life by my experiments on frogs, in which I
the animals breathe for several hours in hydrogen; after a time respiration ceased,
gh life was not extinct. For a time the respiratory movements were renewed
the vessel in which the animals were included was agitated; but, after a longer
d had elapsed, this was no longer the case. If, after being thus confined in
gen for two or three hours, the frogs are taken out and exposed to the atmosphere,
appear perfectly dead; not the least sign of motion or sensation is observable in
. The heart being laid bare, if it is found to have ceased to beat, the animal will
vive. If it still beats, though at intervals of half a minute or a minute, the frog
generally recover without any external stimuli being applied, merely from the
al oxidation of the blood in the vessels of the lungs, the want of which arteria-
n was the cause of the asphyxia. The blood impregnated with oxygen, however
the action of the heart, must at length reach the brain and the medulla oblongata,
then begins again to emit nervous influence. The first signs of the revival of
og, which lies quite motionless, is the retraction of the extremities when the skin
ched; after a short time it is seen to respire at long intervals, and in a few hours
ite lively. The cause, therefore, of the first excitement, and of the continued
of the medulla oblongata in determining the respiratory muscles to action, is
terial blood.*

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he arguments adduced by Professor Müller appear to the translator to be by no means
ent to refute the opinion, that the respiratory movements are the result of reflex ner-
ction excited at first by the contact of the air with the surface of the new-born infant,
terwards by sensitive impressions in the lungs. The continuance of the respiratory
nents in animals after the division of the nervi vagi may be due, as Dr. Hall supposes,
transmission of voluntary influence from the brain to the respiratory muscles; since
ation will not go on, he states, when both nerves are divided and the cerebrum removed,
h either of these operations may be performed singly without checking the movements;
at is perhaps more probable, the sensitive impressions in the lungs, which are usually
yed to the medulla oblongata by the nervi vagi and sympathetic simultaneously, may
e transmitted solely by the pulmonary branches of the latter nerve, which is the ex-
ion proposed by M. Grainger (on the Spinal Cord, p. 89), and Dr. J. Reid (Edin. Med.
urg. Journ. No. xlix.) The last named physiologists have shown by experiments that
the nervi vagi have been divided, animals still feel the sense of suffocation, the "besoin
pirer," when the supply of air to their lungs is interrupted. Again, the fact that a frog
ed of its skin or immersed in water will continue to breathe, and the circumstance of
uor amnios,—a fluid of the same or nearly the same temperature as the body of the
—not exciting in it respiratory movements, do not prove that the impression made on
taneous nerves by the cooler air when the fœtus escapes from the uterus, may not be
citing cause of the first inspiration. Such was the explanation of the first inspiration
ed by Sir G. Blane, and it is in some measure confirmed not only by the well-known
at cold water or cold air suddenly coming in contact with the surface of the body gives
a deep inspiration, but also by an interesting observation made by Dr. Heming, of a
just born apparently asphyxiated beginning to breathe when the cool air was admitted
sing the bedclothes. (Dr. Hall's Memoirs on the Nervous System, p. 88. A similar
ost extraordinary case is related by Dr. Wagner. Medicin. Zeitung, Jan. 1838. Brit.

2. What regulates the rhythm of the respiratory movements?

In the muscles of the extremities the power of continued action is evidently much greater than in the muscles engaged in respiration; thus we can continue standing or bear a weight for a long period, but can prolong the movement of inspiration or that of expiration only for a very limited time. Any muscular motion, however, may be persisted in for a very long period, if made to alternate with other motions. It is not, therefore, the nervous principle that is deficient in these cases, for there is nervous influence sufficient for other muscular actions: the defect must be either in the conducting power of the nerves, or in the contractility of the muscles; one or the other of which, or perhaps both, are exhausted by the movement performed. The regular alternation of inspiration and expiration, and the regular succession of the three acts in the respiration of frogs, show pretty distinctly that neither of the preceding modes of explanation is sufficient to account for them; but that some unknown influence is in operation in the medulla oblongata, which causes each movement of the nervous principle towards the inspiratory muscles to be followed by a motion of the same principle towards the muscles of expiration, and *vice versâ;* so that, as in a pendulum or balance, the movement in one direction necessitates the movement in the opposite direction.

The respiratory movements are not the only periodic automatic muscular actions of daily occurrence which are due to the influence of the central organs of the nervous system. The motions of the muscles of the eye and of the iris during sleep present us with another example of these automatic muscular actions. During sleep the eye is turned somewhat inwards and upwards, and the iris is much contracted, although light is quite excluded. The eye takes this position even before sleep has come on; and the position of the double images which a person sees when he finds himself on the point of falling asleep, proves that the eyes are turned inwards.

Automatic movements of the animal system with a persistent type. The sphincters of the animal system.—Although we have voluntary power over these muscles to strengthen their contraction, yet their action continues independently of volition during sleep as well as in the waking state, and it cannot be voluntarily interrupted, except by exerting a counter pressure against them by their antagonist muscles. The principal sphincters of the animal system are the sphincter ani and the sphincter vesicæ, which is to a certain extent subject to the animal system of nerves. The force and impulse to contraction of these muscles are derived from the spinal cord. Injuries of the spinal cord cause their permanent relaxation, and the consequent involuntary escape of the fæces and urine; this relaxation of the sphincters sometimes also occurs under the influence of depressing passions, which have the effect of weakening the power of the cord. Dr. Hall has shown that the sphincter ani of the turtle remains contracted as long, but only so long, as the lowest portion of the spinal cord is left uninjured.

The action of the sphincters must be owing to an incessant motor excitement of their nerves. In considering the antagonistic muscular action, however, we shall become acquainted with facts which prove that not the sphincters alone, but indeed all the muscles of the animal system, are subject to this constant motor excitement.

We have thus seen involuntary movements partly of periodic character, partly persistent, which are dependent on the influence of the brain and spinal cord. The same phenomena are observed as symptoms of disease of the central organs of the nervous system; persistent as well as intermittent muscular spasms, muscular contractions often occurring at very regular intervals, involuntary motion of the head to and fro, trembling of the limbs and the tonic cramps returning at regular periods, are expressions of morbid states of those organs. It is not known why the motions assume these characters; it has been observed merely that the enduring contractions more generally attend the diseases of a completely local and fixed nature, although every kind of disease of these organs is capable of giving rise to periodic convulsive affections. As a general rule, indeed, nearly all affections of the nervous system which are attended with muscular contractions come on in paroxysms; and even inflammation

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and For. Med. Rev. April. 1838.) The theory of Professor Müller, that the cause of the first respiration is the impression made on the medulla oblongata by the arterial blood, is clearly open to the objection that the blood could not be rendered arterial, and therefore could not excite the medulla oblongata, until respiration had been at least once performed.

spinal cord, though the cause has here a uniform action, gives rise to tetanic
ılsions, which occur in paroxysms. These phenomena, together with the periodic
cter of the attacks of epilepsy, while the operation of their causes is constant,
to show that the excitability of the nervous centres is exhausted by the constant
ssion of morbid irritation, just as the excitability of the nerves is temporarily
ınder the influence of impressions which excite them, in consequence of the
e produced in the nervous matter by the excitement, and that the power of re-
depends in both cases on the excitability being restored by rest. The fading
of the image of a coloured spot on which the eyes are long fixed, and its reap-
nce after an interval, and the periodic daily return of the states of sleep and
ıg in the sensorium, are phenomena which are typical of all such healthy or
d periodic actions; for in these instances also the reaction ceases at intervals for
, although the exciting impressions are constantly the same.

Antagonistic movements.—The action of muscles is not restricted
eir occasional contraction when excited by discharges of nervous
ence. There are grounds for believing that the muscular fibres,
cularly those of the animal system of muscles, are constantly in a
of slight contraction, even during their apparent repose. The re-
on of divided muscles in a living body, and, still more, the mani-
contraction of muscles of which the antagonists are divided or
ysed, are in favour of this opinion. When the muscles of one
l half of the face are paralysed, those of the opposite half draw
atures towards their side. The tongue, when one-half of it is
ysed, is always drawn to the opposite side; and in cases of
val of the middle portion of the lower jaw, whereby the muscles
h draw the os hyoides and tongue forwards,—namely, the ante-
elly of the digastricus, the mylo-hyoideus, the genio-hyoideus, and
enio-glossus,—lose their fixed point of attachment, the os hyoides
ıwn backwards by the stylo-hyoideus, and the tongue by the stylo-
us, so forcibly, that great danger of suffocation arises. Hence it
d appear that the state of inaction of the different parts of our
does not indicate an absolutely relaxed condition of the muscles,
ather that the different groups of muscles antagonise and balance
other; and that when the position of a part is changed from the
ım state of apparent rest, one or more of the muscles, already in
e of antagonistic action, are merely thrown into more powerful
action.

e antagonism of muscular motions is of great pathological import-
Distortions are produced by the balance of the action of muscles
destroyed. Clubfoot, for example, which may take its rise dur-
ıe first months of pregnancy as well as after birth, is frequently
to the proper balance in the antagonistic action of the muscles
ı elevate the inner and outer borders of the foot being lost, and is
cured by restoring the balance of action. Either the peroneal
es which elevate the outer border of the foot are partially para-
, or the muscles which raise the inner border are in a state of
ılytic contraction." In either case the foot rests on its outer
n, and is drawn inwards by the tibialis posticus muscle. After a
however, the position of the bones forming the joints is altered;
s naviculare is generally turned inwards, and the head of the
alus, left partly exposed, forms a prominence on the dorsum of the
In pes equinus, in which the heel is drawn up and the foot rests

on the toes, the gastrocnemii are tensely contracted, and nevertheless sometimes atrophied. A contracted state and atrophy of the muscles are not incompatible with each other. There is a kind of paralytic loss of power in muscles which is combined with contraction;* we have seen the gastrocnemii both contracted and atrophied at the same time.

Curvatures of the vertebral column certainly in many cases arise from scrofulous inflammation of the intervertebral ligaments and vertebræ, producing softening, enlargement, suppuration, and loss of substance, but still more frequently they are owing to loss of balance in the action of the muscles of the trunk. That the curvature is of the latter kind may be known by the absence of the signs indicating rachitis, and by the affection being benefited by gymnastic exercises. These spinal curvatures are, therefore, analogous to clubfoot and pes equinus. In tubercular suppuration of one lung, the thorax on that side is not elevated in respiration, because the lung is incapable of distension; the thoracic muscles of that side are not really paralysed.

4. *Movements arising from reflex nervous action.*—The nature of the reflected motions has been already fully investigated and explained. (See Book IV. sect. III. cap. iii.) They include all muscular actions which arise from impressions on sensitive nerves exciting motor nerves to action through the intervention of the brain and spinal cord. They arrange themselves into two principal groups.

a. Reflected motions of the animal system.—These are the reflex motions of muscles which are under the influence of cerebro-spinal nerves; the impression which excites them may be made either on animal or on organic nerves; for example, in the skin or in the intestinal canal. Coughing from irritation of the mucous membrane of the lungs and larynx, vomiting from irritation of the mucous membrane of the pharynx, stomach, or intestine, and the contraction of the iris from irritation of the optic nerve, are examples of these reflex motions, of which we have described innumerable instances in the chapter on nervous reflexion, p. 552.

b. Reflected motions of the organic system.—The movements of the organic involuntary muscles under the influence of impressions propagated to the brain and spinal cord, whether from parts supplied by cerebro-spinal nerves, or from organs under the influence of organic nerves, have been considered at page 567. The motion of the heart can be affected by impressions made at any part of the body, the spinal cord being the medium of transmission of the influence. The various symptoms of fever are probably due to the impression communicated from some one organ to the spinal cord, and perhaps to the brain also, by organic nerves (see p. 611).

5. *The associate or consensual movements.*—These phenomena have already been considered generally, and their cause investigated (p. 533). Their peculiarity consists in the voluntary impulse to one motion giving rise to the production of other motions contrary to, or independently of, the will; thus, whenever the eye is voluntarily directed inwards, the iris contracts. The less perfect the action of the nervous system, the more frequently do associate motions occur. The motions of the irides, of the

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* See Ollivier, Traité de la Moëlle épinière et de ses Maladies, t. ii. p. 709.

les of the ear, of the eyelids, and of the extremities, in the attempt to effect
sed motions, are examples of such association (see p. 583–4).

me of the most remarkable facts illustrating the association and antagonism of
ular actions are presented by the muscles which move the eyes. The corre-
ding branches of the third or motor oculi nerve of the two sides have a remarkable
e tendency to consensual action, a tendency which cannot be ascribed to habit.
two eyes, whether moved upwards, downwards, or inwards, must always move
her; it is quite impossible to direct one eye upwards and the other downwards at the
time. This tendency to consensual motion is evidenced even from the time of
; it must, therefore, be owing to some peculiarity of structure at the origins of
wo nerves. There is an innate tendency and irresistible impulse in the corre-
ding branches of the third nerve to associate action; while in the sixth nerves not
is this tendency absent, but the strong action of one of these nerves is incom-
le with the action of the other. These innate tendencies in the third and sixth
s are extremely important for the function of vision: for if, in place of the sixth
s, the external recti muscles had received each a branch of the third nerve, it
d have been impossible to make one of these muscles act without the other; one
or example, could not have been directed inwards while the other was directed
rds, so as to preserve the parallelism or convergence of their axes, but they
d necessarily have diverged when one rectus externus had been made to act
tarily. These considerations enable us to understand perfectly the hitherto
atical fact that in all vertebrata the external rectus muscle receives a special
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the same way we may explain why the superior oblique muscle has received a
l nerve (the fourth nerve or n. trochlearis), which likewise has no tendency to
nsual action with the nerve of the other eye. It is necessary, however, first to
nine the action of the oblique muscles. The inferior oblique moves the pupil
ds and upwards; this can be very easily demonstrated by laying bare the muscle
the front, the eye and orbit being undisturbed, and by then drawing the muscle
ds its point of origin. The superior oblique muscle rolls the eye downwards
mewhat outwards. Sir C. Bell (*Nervous System*, 8vo. 1824, p. 312,) has proved
y experiments on animals and on the dead human subject. The two superior
e muscles have no tendency to associate motion with each other; the fourth
in this respect resembles the nervus abducens of the external rectus. When one
directed downwards and outwards, the other eye is not also directed downwards
twards, but downwards and inwards; this is the case from birth upwards; it
that the motion of the superior oblique of one eye through the influence of the
aris is incompatible with the action of the corresponding nerve and muscle of
er eye. It is not so with the inferior oblique; the branch of the third or motor
erve, by which it moves the eye upwards and inwards, has a tendency to con-
l action with its fellow nerve of the opposite side; the motion of the eye up-
and inwards takes place therefore simultaneously on the two sides; it does so
involuntarily during sleep. This position, which the eye takes during sleep,
so in hysterical paroxysms, may be regarded as the effect of the simultaneous
of all the branches of the *nervus motor oculi*. Muscles, we have seen, (page
are slightly contracted even in the state of rest; and, if we suppose all the
es of the motor oculi nerve to be in a state of slight excitement, both eyes
necessarily be turned upwards and inwards. The superior and the inferior
would balance each other's action; the internal rectus would draw the eye in-
and the inferior oblique upwards and inwards; the corresponding branches of
rd nerve which supplies these muscles being consensual in their action, both
ould be simultaneously directed upwards and inwards.

us consider another effect which would have resulted if the rectus externus
had, in place of the sixth nerve, received a branch of the third nerve: had such
e case, the simultaneous direction of one eye upwards and inwards, and of the
pwards and outwards, which so often happens, would have been impossible.
the inferior oblique, and the simultaneous action of the superior and internal
t muscles, directed the one eye upwards and inwards, the same muscles, owing
association of action, would have given the other eye the same direction; it

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* Compare Jessen, Beiträge z. Erkenntniss d. psychisch. Lebens. 1831, 183.

could not have been directed upwards and outwards. Hence it was necessary that there should be a special nerve having no tendency to associate action with its fellow nerve, but capable, by the stronger contraction of the external rectus which it supplies, not only of preventing the second eye from being carried upwards and inwards by the inferior oblique and superior and internal straight muscles acting consensually with the same muscles of the first eye, but also, with the aid of the superior straight muscle, of carrying it upwards and outwards. The same remarks apply in the case of the motion of the one eye downwards and inwards, and of the other eye downwards and outwards. If one eye be turned downwards and inwards by the rectus inferior and the rectus internus, the other eye is turned downwards and outwards by the rectus inferior and rectus externus, aided by the obliquus superior, which being also supplied by a special nerve,—the fourth,—no tendency to consensual movement in the corresponding muscle of the opposite eye is excited. The fourth nerve—nervus trochlearis—belongs also to the nerves of expression.

The associate motion of the iris, when the motor oculi nerve is thrown into action, has been described and explained at page 593.

The organic muscles also are, in some measure, subject to the laws of association. At pages 568-9, reasons are given for believing that the increased frequency and force of the heart's action during muscular exertions of the body is owing to this cause. The action of the voluntary muscles has an influence on that of the intestinal canal; neglect of bodily exertion is often productive of torpidity of the bowels; every one is aware how beneficial muscular exercise is in preserving the regularity of the muscular action of the intestines and regularity of excretion.

6. *Movements dependent on certain states of the mind.*—There are three classes of movements of this kind: 1, those dependent on mere ideas passing through the mind; 2, those arising from passions or the affections; and, 3, voluntary movements.

a. Movements excited by ideas.—Certain groups of muscles of the animal system are in a constant state of proneness to involuntary motion, owing to the susceptibility of their nerves, or rather the excitability of the parts of the brain from which they arise. This is the case with all the respiratory nerves, including the facial nerve. This excitability, this tendency to the discharge of nervous influence, is evidenced in the sneezing which occurs occasionally from internal causes; but the respiratory muscles may be excited to action merely by particular states of the mind.

Yawning, inasmuch as it can be excited by the mere idea, or by seeing or hearing another yawn, belongs to the same class of movements. The disposition to the movements of the features and the respiratory muscles that constitute yawning, exists previously; and it becomes manifested when the idea gives to the nervous principle the determinate direction.

b. Movements due to the passions of the mind.—It is principally the respiratory portion of the nervous system which is involuntarily excited to the production of muscular actions by passions of the mind. Here again we see that any sudden change in the state of the brain, propagated to the medulla oblongata, immediately causes a change of action in the respiratory muscles, through the medium of the respiratory nerves, including the respiratory nerve of the face. There are no data for either proving or refuting the hypothesis that the passions have their seat of action in a particular part of the brain, whence their effects might emanate. But these effects are observed to be transmitted in all directions by the motor nervous fibres, which, according to the nature he passion, are either excited or weakened in action, or completely lysed for the time.

he exciting passions give rise to spasms, and frequently even to ulsive motions affecting the muscles supplied by the respiratory facial nerves. Not only are the features distorted, but the actions e respiratory muscles are so changed as to produce the movements ying, sighing, and sobbing. Any passion of whatever nature, if of cient intensity, may give rise to crying and sobbing. Weeping may roduced by joy, pain, anger, or rage. During the sway of depressing ions, such as anxiety, fear, or terror, all the muscles of the body me relaxed,—the motor influence of the brain and spinal cord being essed. The feet will not support the body, the features hang as out life, the eye is fixed, the look is completely vacant, and void xpression, the voice feeble or extinct. Frequently the state of the ngs under the influence of passion is of a mixed character; the mind able to free itself from the depressing idea; yet the effort to con- this gives rise to an exciting action in the brain. In these mixed ions the expression of relaxation in certain muscles,—in the face, xample,—may be combined with the active state of others; so that eatures are distorted, whether in consequence merely of the antago- g action of the opposite muscles being paralysed, or by a really ulsive contraction. Frequently also, both in the mixed and the essing passions, some muscles of the face are affected with tremors. voluntary motion of a muscle half-paralysed by the influence of ion is necessarily of a tremulous character, in consequence of its g no longer completely under the influence of the will. We expe- e this particularly in the muscles of the face when, during the sway depressing or mixed passion, we endeavour to excite them to ntary action; the muscles of the organ of voice also, under such mstances, tremble in their action, and the words attempted to be ed are tremulous.

he nerve most prone to indicate the state of the mind during pas- s is the facial; it is the nerve of physiognomic expression, and its re of action becomes more and more limited in different animals, in ortion as the features lose their mobility and expressive character. he completely different expression of the features in different pas- shows that, according to the kind of feeling excited, entirely dif- t groups of the fibres of the facial nerve are acted on.* Of the e of this we are quite ignorant.

e disturbed action of the heart during mental emotions is a remark- instance of the influence of the passions over the movements of ns supplied by the sympathetic nerve.

Voluntary movements.—The cerebral and spinal nerves are alone ble of exciting voluntary motion. The history of cases of paralysis disease of the spinal cord shows that the fibres of the spinal nerves ontinued upwards to the medulla oblongata, and that the will has irect action on them at any other part of their course than in the

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On the imitative movements, consult Huschke, Mimices et Physiognomices nent. Physiol. Jena, 1821.

medulla oblongata, which is the source of all the voluntary movements. Again, the origin of the greater number of the cerebral nerves from that part of the nervous centres, and the possibility of tracing the roots of motor nerves apparently arising from other parts of the brain to the same point, as well as the history of lesions of the brain, prove that the cerebral motor nerves also receive their voluntary incitement to action from the medulla oblongata.

The fibres of all the motor, cerebral, and spinal nerves may be imagined as spread out in the medulla oblongata, and exposed to the influence of the will, like the keys of a piano-forte. The will acts only on this part of the nervous fibres; but the influence is communicated along the fibres by their action, just as an elastic cord vibrates in its whole length when struck at any one point. It is in the present state of our knowledge—and perhaps always will be—impossible to determine how, by an exertion of the will in the medulla oblongata, the nervous fibres are excited to action. All that we can do is, to consider the fact in its greatest simplicity.

CHAPTER II.

OF THE COMPOUND VOLUNTARY MOVEMENTS.

By the compound voluntary movements we understand all combinations of movements in determinate groups, which the mind has a share in producing. The kinds of motion treated of in the preceding chapter may enter as elements into the composition of these combined movements. We have here to consider the simultaneous series of voluntary movements consequent on several series of ideas, the associations of movements, and of ideas with movements, the instinctive movements, and the movements of locomotion.

a. Simultaneous series of movements.—Not only can motion be determined voluntarily for a given object in very different parts of the body at the same time; but voluntary movements for very different objects can likewise be simultaneously performed. It is easy to write and smoke at the same time; a performer on a musical instrument reads the notes both of the song and the accompaniment, calling the muscles of the eyes into action for this purpose, and sings and plays simultaneously.

b. Association of movements and ideas.—The rapidity and easy succession of movements are promoted by their frequent repetition. This is what we call practice. A person who is not practised cannot, in a constant rapid change, interrupt and again renew the same movement, or execute complex movements with regularity. The effect of practice shows that the more frequently the same fibres are thrown into action, the easier does their action become.*

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* The laws of the association of voluntary movements have been so frequently explained, that they are now very generally recognised, even in writings on practical medicine. The phenomena of association have been studied more especially by Dar-

e have to consider this kind of association in two points of view.

Association of movements with movements. Hitherto the invo-
ry consensual or associate movements have been frequently con-
ded with the voluntary associated movements. The former depend
e influence voluntarily directed in the sensorium to the excitement
e nerve extending involuntarily to another. Thus one eye cannot
oluntarily raised without the other being also raised involuntarily.
phenomena are not the result of practice; their cause is innate.
y are observed to the greatest extent in the persons least practised;
the object of practice, and the education of the muscular move-
ts, consist partly in learning to confine the action excited by the
to single groups of nervous fibres. The result of exercise or prac-
with respect to these movements is therefore the diminution of the
ency to the involuntary association. It is quite otherwise with the
ciation of voluntary movements. Here practice developes in the
cles the capability for rapid succession or simultaneous execution
ovements, when the muscles as yet have but little proneness to
association. The effect of practice is, therefore, in this case, the
reverse of its result in the case of the involuntary associate move-
ts. Practice diminishes or annuls the innate tendency to involun-
association of movements, while it renders the voluntary associa-
of several muscles in action more easy.

Association of ideas and movements.—The connection between
s and movements is sometimes as close as that between different
s; thus, when an idea and a movement have frequently occurred in
ection with each other, the idea often excites the involuntary pro-
tion of the movement. Hence it is that a threatening movement
re the eyes, even the passing of another person's hand in front of
n, causes the eyelids to be involuntarily closed; that we are accus-
ed always to accompany the expression of certain ideas with certain
ures, and that we involuntarily move our hands to catch a falling
y. It is a general rule that the more frequently ideas and move-
ts are voluntarily associated together, the more prone are the
ements to be excited by those ideas rather than by the will, or to
withdrawn from the influence of the will.

he association of movements with certain ideas is not an isolated
of its kind, even if we do not take into account the frequent asso-
ion of ideas with each other. Ideas do not act merely on the motor
aratus by which they are expressed; they as frequently affect the
ns of sense, which then present sensorial impressions or images of
ideas. There is a great difference between the idea of a disgusting
ation and the sensation of disgust itself, and nevertheless the mere
of a nauseous taste can excite the sensation even to the production
omiting. The quality of the sensation is a property of the sensitive
re, which is here excited without any external agent. The mere
t of a person about to pass a sharp instrument over glass or porce-

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, and are described in his Zoonomia, vol. i. Compare also Reil, Fieberlehre, iv.
09; Reil, von der Lebenskraft; Reil's Archiv. i.; and Brandis, Versuch über die
nskraft. Hannover, 1795.

lain is sufficient, as Darwin remarks, to excite the well-known sensation in the teeth. The mere thinking of objects capable when present of exciting shuddering, is sufficient to produce that sensation of the surface in irritable habits. The special properties of the higher senses, sight and hearing, are rarely thus excited in the waking state, but very frequently in sleep and dreams; for, that the images of dreams are really seen, and not merely present in the imagination, any one may satisfy himself in his own person by accustoming himself regularly to open his eyes when waking after a dream. The images seen in the dream are then sometimes still visible, and can be observed to disappear gradually. This was remarked by Spinoza, and I have convinced myself of it in my own person.*

c. Instinctive movements.—The combined movements, of which the nature is most obscure, are incontestably the instinctive. All those acts of animals are instinctive, which, though performed voluntarily, do not nevertheless depend primarily on the mere will of the animal, which have an object according with the wants of the organism but unknown to the animal, and of which the hidden cause, acting in accordance with the design of the system, incites the animal to the necessary acts by presenting to its sensorium the "theme" of the voluntary movements to be executed in detail by the influence of the will. When incited by instinct, we are conscious only of feelings and impulses to determinate acts. And these instinctive impulses in the human subject are few; the impulse to the movements of sucking in the infant is an instance. The acts which lead to the exercise of the sexual impulse are in animals generally excited by instinct; in man this is certainly only in part the case. Even admitting the embrace of forms which excite the feeling of love to be the result of an impulse implanted in us, the first of our race undoubtedly learnt the rest by experience. The number of the instinctive acts is great in animals in proportion to their incapability of accomplishing the design for which their species was created by their mental powers. This is not the place to recount the great number of the instinctive acts connected with the migration of animals, the construction of nests and dwellings, the formation of webs, and the rearing of young.

The cause of instinct appears to be the same power as that on which the first production of the animal, and the perfection of its organisation in unison with an eternal law, depend.† The instinctive acts of animals show us that this ~~power, which, inde~~pendent of any organ, forms the whole organisation with reference to a determinate purpose and in accordance with an unchanging law, has moreover an action beyond this; they prove that it influences the voluntary movements. That which is effected by the instinctive movements is equally in accordance with a determinate purpose, and as necessary for the existence of the genus and species as the organisation itself; but while, in the case of the organisation of the being, the object attained formed part of the organism, in the case of the instinctive movement it is something in the exterior world; the mental power of the animal is incited by the organic creative force to conceive, and to attempt to attain, some special object. The primary cause of instinct is therefore not seated in any one organ, but is identical with the creative force of the organisation, the operations of which are guided by an unvarying law and a rational principle. The influence of this force in the production of instinct is, however, first manifested in the sensorium. The expression of Cuvier with reference to instinct is very correct. He says, that animals in their acts of instinct are impelled by an innate idea,—as it were, by a dream.

From the acts due to instinct, we must distinguish certain others which many animals are able to perform with great precision even during sleep after they have by previous practice gradually acquired the necessary ability. Many birds sleep standing

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* See Gruithhuisen, Beiträge zur Physiognosie u. Eautognosie. München, 1812; and J. Müller, über die phantastischen Gesichts erscheinungen. Coblenz, 1826.

† The attributes of the creative organic force or power have been considered at pages 31–2.

They preserve their equilibrium with the greatest certainty, and there
ıe force exerted in these acts, though the sensorial operations of the sen-
te suspended. Sleep-walking is a similar phenomenon. It is not instinct
somnambulist, but the faculty of walking safely acquired by experience,
he continues to exercise even during sleep. All the knowledge acquired
ınd experience with reference to maintaining his balance is put in prac-
he operation of his mind alone, and not by instinct, that he is prevented
but his sensorium is active in one direction only, and in no others; and
ıce of his being, in consequence of this limited action of his faculties,
nger, renders him secure, and carries him safely past precipices. These
e indeed not so difficult of explanation as at first sight appears. The
which a person walks over a moderately sloping surface depends en-
nowing that it is not at a great elevation. The same sloping surface on
pears dangerous and difficult to ascend; and provided a person does not
r in the last case, he will pass over the ascent as securely as if it were
ınce only from the surface of the earth.

linate movements.—Although the movements of locomo-
pendent on the will, the appropriate combination of the
ıscular acts necessary for them appears, nevertheless, to be
ore easy by some internal disposition of the nervous system,
ems to subsist between the nervous centres, the groups of
their nerves, a harmony of action dependent on original
This idea is suggested by the experiments on the functions
ellum and the spinal cord. Decapitated birds are seen to
ıds of attempts at locomotion. The same has been observed
lthough they have not the character of voluntary move-
ed by the influence of the brain, still there prevails a certain
een the different acts of such tumultuous movements ob-
ese after decapitation.

riments of M. Flourens, show that there exists not merely
cord a provision for the performance of certain groups of
in unison, but that the cerebellum more especially rules
nbination of the muscular actions required for locomotion
25 and 638). Injuries of the cerebral hemispheres, or their
l not deprive the animals of the power of executing com-
nents. But the removal of the cerebellum produced not
kness, but loss of all harmony in the action of the groups of

CHAPTER III.

OF THE MOVEMENTS OF LOCOMOTION.

*ls are for the most part destitute of locomotion, and are only capable of a
nt of particular parts with reference to the rest of the body.* Some of
are fixed by one part of their body; others lie free.

*ls belonging to very different classes are free during one part of their life,
other.*—Some are first fixed, and afterwards free: of this, the Vorticellæ,
ırenberg, afford us an example. Others are free during the earlier stage
ıd afterwards become fixed, and destitute of all locomotion; of which
rcumstance, the interesting observations of Von Nordmann respecting
f Dugès respecting the Hydrachnida, and of Burmeister on the Cir-
nt us with examples.

ANIMALS ENDOWED WITH LOCOMOTION.

The organs of motion in animals capable of changing their situation are sometimes cilia, bristles, laminæ, or fins, sometimes articulated members. In other cases the movement is effected by the expulsion of fluids previously taken in; by undulatory movements of the different parts of the body, which are in turn fixed, drawn after other parts, or stretched forwards; or by the alternate dilatation and contraction of the whole body.

(*a*) The author in describing the different movements of the animal frame, performed under the guidance of volition, has omitted a description of the passive organs of the apparatus by which these movements are performed. These organs are the bones and articulations, constituting the levers which are set in motion by the muscles, or the active organs. Restricted as I am to limited space, I must content myself with a very slight sketch, and in giving it, shall borrow from one of the lectures on the *Institutes of Medicine*, which I used to deliver at the Philadelphia Medical Institute. Before doing so, however, I will introduce the remarks of the author on the structure of bone.

Bones.—By macerating bones in dilute muriatic acid the earthy matter is extracted, leaving the cartilage. The cartilage of bone has essentially the same structure as permanent cartilage, and before ossification has all its characters. If, after the earthy matter is extracted from the cartilage of bone, the maceration in dilute acid is continued for a considerable time, the cartilage separates into layers like those of an onion. Without this continued maceration of the cartilage, however, these laminæ can be recognised; in the flat bones they are arranged parallel to each other in the plane of the surfaces of the bone, in the cylindrical bones concentrically around the medullary cavity. Besides these concentric laminæ there are other secondary lamellæ, forming concentric circles around the osseous canals, which are seen in great numbers on the surface of any section of bone. These osseous canals with their concentric laminæ lie between the greater concentric laminæ; they contain fatty matter and vessels, and represent in miniature the medullary cavity of the cylindrical bone. The osseous canals, also called medullary canals or Haversian canals, run longitudinally in the cylindrical bones, anastomosing occasionally; in spongy bones they are replaced by medullary cells. Much of the minute structure of bone cannot be seen in the cartilage robbed of the earthy matter, but only in very thin sections of bone itself. When such sections of bone, ground very thin, are examined with the microscope, there are seen numerous oval corpuscules of the form of the corpuscules of cartilage; these are called the osseous corpuscules. From each of these small bodies radiate a number of minute canaliculi, some of which are branched. The diameter of these radiating canaliculi is $\frac{1}{5000}$ to $\frac{1}{3333}$ of a Paris line. They, as well as the corpuscules, appear dark when viewed by transmitted light, while the substance in which they are contained, if the lamina of bone is sufficiently thin, appears quite transparent. If the same laminæ of bone are viewed by reflected light while lying upon a dark surface, the corpuscules and canaliculi appear white; but acids render them transparent, which seems to show that they contain inorganic deposits either in their cavity or in their walls. The principal mass of the calcareous salts, however, must be contained, not in the corpuscules and canaliculi, but in the transparent substance in which they lie imbedded. For when laminæ of bone are boiled with potash, which dissolves all, or the greater part of the cartilage, the calcareous salts are seen still filling the interspaces between the minute radiating canals. Whether the calcareous salts in this part of the osseous substance are united chemically or merely mechanically with the cartilage cannot be decided. The earthy material of bone consists in greater part of phosphate of lime with carbonate of lime, and small quantities of phosphate of magnesia and fluoride of calcium. The phosphate of lime of bone is a sub-salt in a peculiar state of combination, such as is always obtained when superphosphate of the earth is precipitated by excess of ammonia. The phosphate of lime of the urine is a super-salt, and is in a state of solution. In mollities ossium this soluble phosphate seems to be excreted by the kidneys in increased quantity.

Berzelius's analysis of bone of the human subject and ox are as follows:—

	Human bone.	*Bone of the ox.*
Cartilage completely soluble in water	32.17	33.30
Vessels	1.13	
Subphosphate of lime	51.04	55.45
Carbonate of lime	11.30	3.85
Fluate of lime	2.00	2.90
Phosphate of magnesia	1.16	2.05
Soda with a minute proportion of chloride of sodium	1.20	2.45
	100.00	100.00

Schreger states that in the bones of a child the earthy matter constitutes ½, in the bones of an adult ⅘, and in those of an old person ⅞ of the whole mass.*

That the phosphorus and calcium exist in the bones in the state of phosphate of lime, is proved by the affinity evinced by madder, when taken as food, for the bones of living animals, which it colours red.

The animal constituent of bone or its cartilage is composed of gelatin. A remarkable fact, which my investigations have elicited, is, that the cartilage of bone before ossification consists of chondrin, but afterwards of the ordinary gelatin. Bones affected with mollities ossium no longer yield gelatin, but contain a large quantity of fatty matter.

The intimate structure of cartilage has been described in a former Book, p. 106, and its divisions at p. 116.

ORGANS OF SUPPORT.—Man, as well as the other vertebral animals, (mammiferæ, birds, reptiles and fishes,) has an internal skeleton, formed of a great number of bones articulated together and set in motion by the muscles with which they are covered. This skeleton, called the osseous system, serves as a foundation to the animal machine, yields a firm support to all its parts, determines the size of the body, its proportions, forms and attitudes. Without the bones, the body would have no permanent form, and could not easily move from one place to another: they constitute in fact its levers, and transmit the weight of our parts to the earth. The skeleton of the human subject is composed of the following bones: thirty-two vertebræ, of which seven are cervical, twelve dorsal, five lumbar, five sacral, and three coccygeal. Of the ribs, seven pair unite at the sternum by cartilaginous prolongations and are called true ribs; the following five are named false ribs. The cranium has eight bones, viz. one occipital or occipito-basilary, two temporal, two parietal, the frontal, the ethmoid and the sphenoid. The bones of the face are fourteen in number,—two maxillary; two malar, each of which is joined to the maxillary of the same side by a kind of process which forms the zygomatic arch; two nasal; two palatine, the vomer between the nostrils; two spongy bones of the nose in the nostrils; two lachrymal ones at the internal sides of the orbits, and the single bone of the lower jaw or the inferior maxillary. Each maxillary bone has sixteen teeth, viz. four incisors in the middle; two pointed canine adjoining, and ten molar, with a tuberculous corona, (five on each side,) forming in all thirty-two teeth.* The scapula has at the end of its spine or projecting ridge a tubercle, called acromion, to which is attached the clavicle; and above its articulation is a point called the coracoid process for the attachment of some muscles. The radius turns completely on the ulnar or cubitus, owing to the manner of its articulation with the humerus. The carpus has eight bones, four in each row; the tarsus has seven. The remaining ones of the hand and foot, or metacarpal and metatarsal, are easily counted, being the same in number as the fingers and toes. The bones of the pelvis give support to the spinal column above, and have cavities below for the articulation with the femur on each side—which again is articulated with the two bones of the leg,—tibia and fibula.

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* See Hildebrandt's Anatomie by Weber, t. i. p. 316. On the composition of diseased bone, consult Bostock, Medico-Chirurg. Trans. vol. iv.; and on the proportions of animal and earthy matter in different bones, healthy and diseased, Dr. Rees, Med. Chir. Transact. vol. xxi.; and Guy's Hosp. Rep. No. viii.

The articulations which, as we have seen, unite the different bones of the skeleton, are not all intended to allow of motion. Several, as the serrated and squamous sutures and *gomphosis*, are entirely without motion, and are on that account termed *synarthrosis*. All the other articulations, whether the bones are in immediate contact (*diarthrosis* of contiguity,) or whether they are united by a substance interposed between them (diarthrosis of continuity or *amphiarthrosis*), are endowed with a certain degree of mobility. These are the articulations which allow of extensive motion in every direction (diarthrosis *orbicularis* or rotatory), or which move only in two opposite directions (alternate diarthrosis or ginglymus), hinge-like, either by an angle (angular ginglymus) or by executing on each other motions of rotation (lateral ginglymus).

In all the articulations, the osseous extremities are covered by lamina, of a substance less hard than that of bone. These are the articulating cartilages, which answer the two purposes of giving to the ends of the bones the degree of polish necessary to their slipping freely, and to facilitate motion by the considerable degree of elasticity which they possess.

The osseous system is, except at the joints, imbedded in, or covered by, muscles, which are almost always parallel to the bones that they are intended to move. They are really the active, while the bones may be called the passive, organs of motion. The direction of the former, parallel to the latter, which they are to move, makes them act to a disadvantage: the greater part of the muscles are besides inserted in the bones, very near the articulations or the centre of motion, and move them as levers of the third kind, that is, are placed between the fulcrum and the resistance. In addition to this, there is a loss of power in the muscular fibres acting frequently on the aponeurotic covering in place of the tendinous termination; and also in their passing over articulations in their way to the bone which they are to move. Owing to these causes, there is an erroneous misapplication of power and waste of the greater part of it. It has been reckoned, that the deltoid muscle employs power equal to 2568 pounds to overcome a resistance of fifty.†

The intimate structure of the teeth has been described at page 109.

The compensating advantages will be stated at p. 684.

A few words now on the peculiar conformation of the human frame before we speak of its motions and attitudes.

The foot of man is very different from that of all other animals, even the monkey: it is broad, the leg rests vertically on it; the heel is full beneath:—his toes are short and cannot bend to any extent; the great toe longer and thicker than the rest is not an antagonist to them. The foot then is adapted to the support of the body, but it can serve neither for prehension or catching hold, nor climbing: and, as the hands cannot furnish any aid in walking, man is the only animal truly bimanus and bipes, or with two hands alone and two feet alone for separate offices.

The human body is arranged exclusively for a vertical or upright position. The feet furnish a support larger than any other of the mammiferæ: the muscles which retain the foot and thigh in a state of extension are more vigorous, whence the projection of the calf of the leg and the hips: the flexors of the leg have their insertions higher up, which affords the knee a complete extension and leaves the calf more prominent; the pelvis is larger, which separates the feet and gives the trunk a pyramidal form favourable to an equilibrium: the necks of the thigh bones form with their body an angle which augments still more the separation of the feet and enlarges the base of the body: finally, the head in its vertical position is balanced on the trunk because its articulation is nearly beneath the centre of its mass. (*Cuvier, Regne Animale*, t. i. pp. 82–83–84.)

Man then can only support himself with any ease on his feet. He preserves the free use of his hands for the arts, and his organs of sense are situated most favourably for observation. The hands so much favoured on the side of freedom are not less on that of structure. The thumb longer in proportion than in the monkey's gives greater facility for the prehension of smaller objects: all the fingers except the ring one have separate movements, which we do not find in other animals, even in the monkeys. The nails covering but one side of the end of the finger give a support to the touch without in any degree impairing its delicacy. The arms which support the hand have, moreover, a solid attachment by means of their large scapula, and their strong clavicle.

Motion. The human body in its most common position or that of standing has its parts of sustentation and motion placed as follows:

The head intimately united to the atlas forms with it a lever of the first kind, whose point of support or fulcrum is in the articulation of the sides of the substance of the atlas and of the axis, while the power and the resistance occupy each an extremity of the lever, represented the one by the face, the other by the occiput. The point of support being nearer to the occiput than to the forepart of the head, the face tends by its weight to fall forwards: but it is kept in equilibrium by the contraction of the muscles attached to its posterior part. The vertebral column, therefore, supports the head and transmits the weight of it to its lower extremity.

The superior limbs, the soft parts of the neck and thorax, gravitate mediately or immediately upon the vertebral column, which on account of the weight of these parts requires great solidity.

In fact the bodies of the vertebræ, the intervertebral fibro-cartilages and the various ligaments which unite them, form a whole of great solidity. If, again, we consider that the vertebral column is formed of portions of erect cylinders, that it resembles a pyramid whose base rests upon the sacrum; that it presents three curves in opposite directions, which give it many times more resistance than if it had none, we shall have an idea of the resistance of the vertebral column. We also see it support not only the weight of the organs which gravitate upon it, but even frequently very heavy loads.*

The weight of the organs supported by the vertebral column, being felt more at the forepart, muscles placed along its posterior part resist the tendency which it has to fall forwards.

The vertebral column taken altogether represents a lever of the third kind whose point of support is in the articulation of the fifth lumbar vertebra with the sacrum, its power is on the parts which tend to draw the column forwards, and its resistance is in the posterior muscles. It is at the inferior part of this lever,—where the power principally acts, that nature has placed the strongest muscles, that the pyramid represented by the vertebral column has the greatest thickness, and that the vertebral processes are more marked and horizontal,—there, lastly, it is, that we feel fatigue after standing a long time.

The weight of the vertebral column and of the parts gravitating upon it, is transmitted directly to the pelvis, which, resting upon the thighs, represents a lever of the first kind, whose point of support is in the femoral articulations, and whose power and resistance lie before and behind. The pelvis also supports the weight of part of the abdominal viscera.

The sacrum supports the vertebral column, and, acting like a wedge, it transmits equally to the two thighs, by means of the ossa ilii, the weight with which it is loaded.

The muscles which run from the thigh to the posterior part of the pelvis prevent the latter from rising, and are the principal agents of the equilibrium of the pelvis upon the thighs; and nature has hence made them very numerous and strong.

The neck of the thigh, besides its use in motion, is of utility in standing, by directing the head of the thigh obliquely upwards and inwards; whence it supports the vertical pressure of the pelvis, and resists the separation of the ossa ilii, which the sacrum has a tendency to produce.

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* The quantity of elastic substance (intervertebral fibro-cartilage) interposed between the several vertebræ, is not so great as to occasion any insecurity in their connection, yet the aggregate elasticity of the whole renders the vertebral column very springy; so that the head rides upon its summit undisturbed by jars, and as upon a pliant spring. The central inelastic matter admitting of a ready variation of form though not of bulk, serves as a pivot, facilitating the motion of the vertebræ on one another.

In the *Squalus maximus* or basking shark of Pennant, there is in the centre of the intervertebral connection a bag of water, and so great is the elasticity of the substance by which it is surrounded, that when the bag was cut into the expansion of the elastic matter projected the fluid to the height of four feet in a large and perpendicular stream, compressing the bag into a small compass and forcing its sides into numerous wrinkles. *Abernethy's* Lect. III.

The femur transmits the weight of the body to the tibia; but, from the mode in which the pelvis presses upon it, its inferior extremity has a tendency to be carried forwards, while the upper, on the contrary, inclines backwards; whence it follows, that to maintain it in equilibrium on the tibia, powerful muscles are required which may oppose this motion. These muscles are the rectus anterior and triceps femoris, whose action is favoured by the presence of the rotula or patella placed behind their tendon. The muscles of the posterior part of the leg, which are attached to the condyles of the thigh, also contribute to maintain this equilibrium.

The tibia transmits the weight of the body to the foot; the fibula has no share in this. But, for the former bone to fulfil this office properly, muscles are requisite which may oppose the tendency of its upper extremity to be carried forwards. The gemelli and soleus chiefly accomplish this end. The foot supports all the weight of the body, for which it is well calculated by its form and structure; its sole has great extent; its skin and epidermis are very thick. Above the skin is a fatty layer, very thick, especially in those parts where the foot presses on the ground. This fat forms a kind of elastic cushion, calculated to weaken or diminish the effects of pressure from the weight of the body.

The foot does not touch the ground to its whole extent; the heel is the external edge, the part corresponding to the anterior extremity of the metatarsal bones, and the point or pulp of the toes are the points which habitually touch the ground and transmit the weight of the body to it.

The general mode of transmission is as follows:—the tibia transmits the weight of the body to the astragalus, and this to the other bones, chiefly the os calcis and the os scaphoides; from which the pressure is transmitted in part to the ground through the os calcis, and in part to the os cuboides, which, with the scaphoides, press in their turn by means of the ossa cuneiforma, upon the metatarsal bones: these resting upon the ground transmit to it nearly the whole pressure they sustain: the surplus is distributed to the toes, and at length likewise terminates on the base of support. As the pressure of the tibia is felt particularly at the inner part of the foot, the latter has a constant tendency to be thrown outwards, which is prevented by the fibula, and the foot is thereby kept in the straight position requisite for firm standing.

The space between the feet with the surface which they cover is the base of support. The condition of equilibrium for standing erect is, that the vertical line drawn from the centre of gravity shall fall upon one of the points of the base of support. Standing will be so much the more firm as this base is broader, and is more firm when the two feet directed a little outwards and placed upon parallel lines, are separated by a space equal to the length of one of them.

Mechanism of locomotion.—The essential principle of locomotion in its most different forms, swimming, crawling, walking, or flying, and in almost all animals, is, that parts of their body form arches, which in straightening themselves act against a fixed point of resistance. In some cases the arches are formed by the whole worm-like body, as in the crawling and swimming of some animals; in other instances, in place of the arching and straightening of the body, the same is effected by the approximation and separation of the two sides of an angle; in which case one of the sides or branches of the angle, by the resistance it meets with from a solid or fluid substance, affords the fixed point which enables the separation of the two branches or opening of the angle to carry the other parts of the animal forwards. This is the principle of movement in animals with locomotive members, whether these be fins, wings, or legs, and whether they move in water, in the air, or on the ground: for even the air and the water afford resistance to bodies which strive to displace them; and the force exerted in displacing them reacts, in proportion to the resistance they give, on the body of the animal, and imparts to it a motor impulse in a determinate direction. In connection with this subject, the laws of the action of levers must necessarily be considered. Although many varieties of the lever are met with in the limbs of animals, yet they are for the most part so applied that power is lost; thus the muscles in many, indeed in most cases, act on them in an oblique direction, and are besides inserted very frequently near the fulcrum and distant from the moving end of the lever. There are more important objects thus attained than mere beauty of form. Had nature in every limb adopted the arrangement of lever calculated to give the most power, such a complexity, angularity, and awkwardness of form would have resulted, that the increase of impediments to a harmonions co-operation of parts would have caused the expenditure of force to be in the end even greater than it now is. Extent of motion also required that the muscles should not be inserted far from the fulcrum of the lever: for had their insertion been placed nearer the moving extremity of the lever, power would, it is true, have been saved; but, on account of the slight degree of shortening of which muscles are capable, (according to M. Schwann's experiments, at most a third of their length,) extent of motion would have been lost,—the biceps, for example, would not have been able to bring the fore-arm close to the arm, which it can do in consequence of being inserted near the fulcrum. Velocity of motion, also, as well as extent, is gained by this mode of insertion of muscles, for in the same time that the part of the lever immediately acted on passes through a small space, the other end, far removed from the fulcrum and moving force, traverses a much greater space, and moves with proportionate rapidity.*

Swimming.—In swimming, the essential act consists in the straightening of an arch which in becoming straight exerts pressure on the water. If we suppose a flexible and elastic rod of the same size throughout lying in the water to become bent in the middle, and then straightened, the two halves of the arch would strike the water in the oblique direction with equal force, and the straightened rod would not be impelled forwards in the longitudinal direction. The result is the same when two levers of equal size united by a hinge are inclined towards each other and then extended, the mass of the two levers being the same; the power at their middle, which effects their approximation, will move each with equal force towards the other, and a force acting at the same part in such a manner as to extend the joint will move them with equal force from each other. But if the principal mass of the body form one of the levers, the force acting at the point of flexion will tend rather to move the smaller lever towards the larger one than this towards the smaller. While the larger lever will preserve its position in the water, the smaller one, both in flexion and extension, will alter its relative position to the larger mass.

Walking and running.—In swimming, the body is borne up wholly or in part by the water, and its motor power is nearly entirely expended in the act of propulsion. In flying, the body is not supported by the medium in which it moves, and a certain additional amount of force is required to neutralise the tendency to fall after each act of propulsion. In walking, the body is both supported and moved forwards by its own strength; and there is this peculiarity, that the body in this movement is alternately supported on each extremity which is fixed on the ground, while by the other it is propelled forwards. One half of this movement is represented in a boat moved on the water by a pole pushed against the bottom; but what the water effects in supporting the boat is done by the other extremity in the act of walking in the air. In leaping, in which the body for a short space of time is kept suspended in the air by the propulsive force imparted to it, the second act of the movement—that of supporting the weight of the body—does not take place till the spring is completed. In this case, as in flying, the body is kept up by the same movement that propels it forwards; the medium serving for the point of resistance is, however, different, namely a solid body. After the influence of one movement of the wings in flying has ceased, the bird is prevented from falling by a new movement of propulsion; at the end of the movement of leaping, the body is prevented from falling by supporting itself on a solid surface.

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* On the movements of locomotion, consult Borelli, de motu Animalium. Lugd. Batav. 1685. 4.—Barthez, Neue Mechanik der willkührlichen Bewegungen des Menschen und der Thiere. Halle, 1800, 8.

The means by which these movements are performed in the human subject, is the extension of two joints flexed in opposite directions, namely, the ankle and knee-joints. By this act of one extremity the centre of gravity is carried forwards, while the weight of the body is supported towards the end of the movement by the second extremity. The two extremities alternately support and move the body. The movement of propulsion being exerted, not in the middle line, but by both extremities at the side, the extension of the joints gives an impulse not merely forwards, but towards the opposite side. The arm of the side on which the extremity is being extended is each time thrown forwards.

The researches of Dr. Edward Weber concerning the articulations, (*Müller's Archiv.* 1836, p. 54,) and those of MM. E. and W. Weber respecting the movements of walking and running, have made us acquainted with many remarkable facts of a physical nature relating to these movements of locomotion, and with their laws. The physiology of these movements has first received a scientific accuracy from their discoveries. The most important facts which they have established are the following, which I extract from their work.* In the first place, and as a key to many other remarkable facts, we must mention the discovery of Dr. Edward Weber, that the head of the thigh-bone cannot be separated by the mere weight of the limb from the surface of the articular cavity to which it is accurately adapted; but that, in all its motions, it is retained close to the articular surface by the pressure of the atmosphere.

In ascending very high mountains, where the air is greatly rarefied, the muscular force must on that account become more necessary to maintain the articular heads of bones in their proper cavities, and the peculiar kind of fatigue which has been experienced by persons passing over high mountains is probably attributable to this cause.

MM. E. and W. Weber have further pointed out the importance of the pendulum-like oscillations of the legs in walking. If the body be supported on one leg upon a raised pediment, the other leg, being set in motion, will vibrate backwards and forwards like a pendulum. These vibrations may also be produced, if, while standing with one leg upon a level surface, the other leg be bent to such a degree as not to strike the ground in its vibrations. The time of these vibrations, like that of the vibrations of a pendulum, depends on the length of the limb and on the mode of distribution of its weight.

The general mechanism of walking is as follows:—The body is supported by the two legs alternately, and the moment in which each forms the support is immediately succeeded by that in which the heel of the same limb is elevated and the body impelled forward by it. At the time that the foot A gives this movement of impulsion, the body is supported by the leg B, which, however, during the movement of the body forwards in an oblique direction, and while the leg A makes the pendulum-like movement forwards for the new step, proceeds to elongate itself by raising the sole of the foot from the ground, in order to give the body a fresh impulse. The extremity A now becomes the support for the body. The MM. Weber compare the gradual raising of the soles of the feet from the ground to a wheel rolling along the surface. By this movement the step is lengthened by the whole length of the foot. In every step we may distinguish two periods; one in which the body is supported by one leg only, and a shorter period in which both legs rest on the ground. It is only in very quick walking, which nearly amounts to running, that the feet only touch the ground alternately, one ceasing to support the body when the other begins to receive its weight. In ordinary walking there is between the periods in which the body rests on one leg only, a state of transition, which lasts from the moment when the front foot is put to the ground, and that at which the hind foot is quite raised from it. According to the

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* Mechanik der menschlichen Gehewerkzeuge, mit. 17 taf. Gött. 1836–8.

MM. Weber, this period is in slow walking about half as long as that during which the body rests on one leg. The quicker the walk, the shorter is this period.

The trunk is inclined forwards in walking. This position is necessary for walking easily; it is impossible to move forwards a rod balanced perpendicularly on the fingers, without its falling. To walk with the body perpendicular, it would be necessary to exert a constant muscular effort to restore the balance disturbed by the resistance of the atmosphere. In quick walking the trunk is more inclined forwards, while there is only a very short, if any period, at which both feet rest simultaneously upon the ground; and the steps are both longer and quicker. The condition on which all these circumstances in quick walking depend is, as MM. Weber show, the less height at which the two heads of the thigh-bones are moved above the surface of the ground. When the level at which the hip-joints are carried is low, the steps are longer, because the leg with which the step is to be made can be moved farther from the vertical position when its upper extremity is low than when it is high. The step, moreover, is quicker under these circumstances; for, the lower the level at which the head of the femur is carried in walking, the greater is the inclination of the leg which gives the impulse to the body, and hence the greater also is the force and velocity of the movement it imparts. With regard to the number of steps made in a given time, this depends partly on the length of the leg which swings from behind forwards, and partly on the time at which this motion of the limb is interrupted by the foot being put to the ground. The longer the leg, the slower are its oscillations,—that is, if the movement of the limb be not accelerated by muscular effort. Hence, abstraction being made of this power of voluntarily accelerating the movement, there is in every individual a certain maximum of the number of the steps taken in a given time, which cannot with ease be exceeded. This maximum rate of walking without great effort is attained when the limb moving from behind forwards is brought to the ground, after it has already passed through half the extent of its natural oscillation. But the succession of the steps can be rendered slower by allowing the leg to pass through more than half its arc of oscillation before putting it to the ground.

It necessarily follows, from the nature of the movements of walking, that the body must, at each impulse forwards, rise somewhat and then sink again. These vertical undulations are, however, on account of the legs being capable of elongation and shortening, very slight, amounting, according to MM. Weber, to only 32 millimetres (about 1 inch 3¼ lines). The movement of the arms backwards and forwards always takes place in the opposite direction to that of the leg of the same side. The leg, by acting against the ground so as to propel the body forwards, gives an impulse to the whole trunk, which might be expected to cause the opposite leg and both arms to fall forwards. But while the leg of the opposite side, and the arm on the same side with the limb which gives the impulse, move forward, the other arm is thrown backwards. This order of the movements of the limbs, which is maintained so habitually that it is practised without our consciousness, contributes not a little to the preservation of the good carriage and equillibrium of the body. On each side, namely, one limb is thrown forward at the same time; on one side an arm, and on the other a leg; and in this way the defects of movement in the trunk which might be produced by the swinging of the leg from behind forward are corrected.

The circumstance characteristic of running is, that only one leg comes to the ground at a time, while in walking there is a period at which both feet rest on the ground. In quick running, indeed, the body is at one moment of each act supported by neither leg, but is moved through the air for a short space of time by the impulse communicated to it.

Leaping. (*Tiedemann's Zeitschrift für Physiol.* t. iv. pt. i. p. 87.)—The peculiarity of the movement of leaping consists in the body being raised completely from the ground for a longer period than in the other movements of locomotion. When the spring or leap is carried to the utmost, it is effected by the sudden extension of three joints, the hip, knee, and ankle joints, previously flexed in opposite directions. The foot, before the leap, may be applied to the ground by the entire sole, or only by the toes; in the former case, the foot is gradually raised from the ground, from the heel towards the toes, during the movement; if the toes only touch the ground, and the ankle therefore be already in a state of extension, this joint is still more strongly extended. The body is always inclined forwards towards the thighs. When, in a leap made with sufficient force to raise the body to a considerable height from the ground, the three joints of the lower extremities are extended, if no resistance were opposed to it, the length of the body would merely be simultaneously increased at each extremity; but the resistance offered by the ground causes the impulse to be imparted to the centre of gravity of the body, which is thus propelled, in the manner of a projectile, in the mean direction of the joints which are thus extended. The direction which the body takes in leaping does not depend on the inclination of one portion of the extremities only; for instance, it is not necessary for springing in the perpendicular direction that the leg should be nearly perpendicular to the floor, as Treviranus and others have asserted. Whatever inclination the leg may have with reference to the floor, the leap can nevertheless be made either forwards or backwards. The conditions which essentially facilitate the spring backwards are more evident when this movement is made in the most simple manner. Thus, the leap backwards may be made quite independently of any action of the ankle-joint, if, while standing on the edge of the heels of the shoes, the knee previously bent be forcibly extended without any perceptible movement of the hip-joint. In this case the body receives an impulse in the direction of a line drawn between the heel and the hip-joint; and, inasmuch as this line passes behind a perpendicular line falling from the centre of gravity to the heels before the movement was made, the motion given to the body is obliquely upwards and backwards.

The more minute details of the modifications which the extremities of vertebrate animals present in accordance with their destined use in flight, swimming, prehension, climbing, and burrowing, is the province of comparative anatomy. How different are the hand of the ray and that of the horse! in the former the fingers and their phalanges which compose the fin, are in extraordinary number, while the arm and forearm are wanting; in the fish-like mammalia, the cetacea, we again find an excessive number of phalanges, but a short arm and fore-arm are present; the solidungula, as the horse, present the other extreme,—the hand and foot are reduced to a single finger and toe.*

SECTION III.

OF VOICE AND SPEECH.

CHAPTER I.

I. *Of the general conditions for the production of sound.*

The sounds of the voice and speech are not, it is true, the immediate result of muscular action, but of the vibrations of a peculiar apparatus which may be compared to a musical instrument: but as the tension of the instrument necessary for the production of sound, and the height and succession of the tones, are determined by the contraction of muscles, the physiology of the voice and speech will be properly considered in this place. Before, however, entering on the consideration of the human voice itself, we must become acquainted with the general conditions on which the production of sound depends.

A sudden mechanical impulse upon the organ of hearing gives rise to the sensation of sound, which resembles a report if the impulse be violent, or is less intense if the impression be more feeble. The rapid escape of compressed air, or the rapid entrance of air into an imperfect vacuum, produces the sensation of sound, if the concussion of the air be communicated to the organ of hearing. But to produce sounds of uniform character which may be compared with each other, it is necessary that the impulse communicated to the ear should be of a particular kind, namely, a frequent repetition of the same impulse. The difference of sounds as to pitch or sharpness depends on the number of these impulses which occur during a certain time. The cause of the sensation of sound, in most cases, is the communication of the vibrations of sonorous bodies to the interior of the organ of hearing and the auditory nerve. The facts, that sonorous bodies have elasticity either from their attraction of cohesion, as the solid sonorous bodies,—or from their tendency to expansion, as the gases,—or from tension, as the sonorous cords,—and that all these bodies vibrate while in the act of emitting sound, naturally lead to the supposition that the vibrations alone are the essential cause of the sound. It would, however, be very incorrect to imagine that the *oscillating motion or vibration* imparted to the auditory nerve is essential for the production of the sensation of sound. On the contrary, it appears that the immediate cause of the sensation of sound, even when this is excited by the vibrations of sonorous bodies, is really the regular succession of *impulses* which the auditory nerve receives. This is proved by the investigation of those sounds which are produced, not by the vibrations of an elastic body, but by a series of mere impulses quickly succeeding each other. If a piece of wood be held against the teeth of a rapidly revolving wheel, every stroke of the teeth of the wheel will be communicated as an impulse to the ear, and produce the sensation of sound. If, however, the wheel be now made to revolve more rapidly, so that the separate strokes on the wheel cannot be distinguished, in place of a succession of shocks, a continuous sound will be perceived; the pitch of which will be higher as the rapidity of the wheel's motion is increased. Still greater interest, in reference to the theory of the essential cause of sound being a quick succession of impulses, attaches to the tones which may be produced by a current of a gas, or liquid, such as water or quicksilver, interrupted at regular and very short intervals, particularly since liquids are not elastic, and therefore not capable of producing sound by vibration. Thus, in the siren, an instrument invented by M. Cagniard la Tour, a rapidly revolving wheel interrupts momentarily, and at successive intervals of very short duration, the escape of a fluid from the opening in the body of the instrument. Even when the revolving wheel is under water, and interrupts at regular and frequent intervals the current of water supplied by pressure from below, the impulses produced by the periodic escape of the fluid, if they follow each other in sufficiently rapid succession, give rise to a clear sound, of which the pitch is higher in proportion to the rapidity of the succession of the impulses, or moments of interruption of the current.

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* On the adaptation of the hand to its uses in the different orders of animals, consult Sir C. Bell's Bridgewater Treatise on the Hand. London and Philadelphia.

II. *Of the voice, of the organ of voice, and other means for the production of sound in man and animals.*

The preceding and other analogous facts afford us data for correctly estimating the means which contribute to the production of voice and other sounds in man and animals. We have three principal classes of musical sounds to consider; 1, the voice of man and quadrupeds; 2, sounds formed in the mouth; 3, the voice of birds. These three classes of sound are produced by different instruments and in different parts. The different sounds of the voice in man and mammalia are generated in the larynx, and are somewhat modified in quality by the parts in front of the larynx, through which the air passes. In whistling, we give rise to an entirely different series of sounds, which have their source in the lips and cavity of the mouth. The voice of birds again has another seat; it is produced not in the superior, but in the inferior larynx, which occupies the lower extremity of the trachea at its point of division into the bronchi. In the few other vertebrata below birds which have a voice, as the frogs and toads, the sound is generated in the proper larynx, as in man and mammalia. Besides the organs of voice which prevail extensively through entire classes of animals, there are other special instruments of sound in some animals, even among the lower classes; the examination of these, however, would lead us too far from our proper object.*

1. *Of the Human Voice.*

A. *Of the human organ of voice.*—If any question relating to the human voice have been determined with certainty, it is that regarding the part of the air-passages in which the voice is formed. Observations on living subjects, as well as experiments on the larynx taken from the dead body, prove that the sound of the voice is generated at the glottis, and neither above nor below this point. If an opening exists in the trachea in the human subject, or if an opening is made in this situation in an animal, the sound of the voice ceases, but returns on the opening being closed. This experiment has been often made, and its accuracy is beyond a doubt. An opening into the air-passages above the glottis, on the contrary, does not prevent the voice being formed. M. Magendie, moreover, has convinced himself that the voice is not lost, though the epiglottis, the superior ligaments of the larynx, and the upper part of the arytenoid cartilages be injured. He has also seen in living animals, whose glottis he had laid bare, that during the emission of sound the inferior ligaments of the larynx, which bound the fissure of the glottis, were thrown into vibration. We know also that injury of the laryngeal nerves supplying the small muscles, which alter the states of the aperture of the glottis and make tense the vocal cords, puts an end to the formation of vocal sounds; and that, when these nerves are divided on both sides, the loss of voice is complete. Again, if we attempt to produce sounds by forcing a current of air from the trachea through the larynx in the dead human subject,—an experiment in which a person the most unpractised may succeed, provided the vocal cords be in some degree tense and the aperture of the glottis narrowed,—we shall find that the sounds are produced, whether the part of the trachea which serves to convey the current of air to the larynx be long or short; and even though it be entirely wanting, and the air be forced immediately through the glottis from the lower extremity of the larynx. Again, a larynx thus cut from the body may be freed from all the parts lying in front of the glottis: the epiglottis, the upper ligaments of the larynx, the ventricles of the larynx between the superior and inferior, or vocal ligaments, the greater part of the arytenoid cartilages, namely, their upper part, may be all removed; and if the inferior ligaments or vocal cords only remain, and be approximated so that the fissure of the glottis be narrow, clear tones will be produced by forcing air through it from the trachea. All these facts establish the correctness of the view which regards the glottis and the inferior laryngeal ligaments or vocal cords which form the immediate boundaries of the glottis as the essential source of the voice; the trachea as the "wind-chest"† of the wind instrument; and the vocal tube in front of the glottis, comprehending the upper part of the cavity of the larynx, and the air-passages thence upwards to the openings of the mouth and nostrils, as the tube of a musical instrument by which the sound may be modified, but not generated.

The parts forming the boundaries of the glottis, namely, the vocal cords, first claim our attention. They are elastic, and can be made tense by the depression of the thy-

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[*] The authors who have written concerning the human voice are: Dodart. Mém. de l'Acad. de Paris, 1703, 1706, 1707.—Ferrein, ibid. 1741.—Magendie, Précis élèment. de Physiol.—Physiology translated by Milligan.—Biot, Précis Element de Physique experiment, Paris, 1824, t. i. p. 457.—Fechner, in his translation of Biot's Experimental-physik. ii. p. 149.—Savart, in Magendie's Journ. de Physiol. v.—Liscovius, Theorie der Stimme. Leipz. 1814.—Chladni, in Gilbert's Ann. lxxvi. p. 187.—Mayer, in Meckel's Archiv. 1826.—Bennati, Recherches sur le Méchanisme de la Voix Humaine, Paris, 1832.—Muncke, in Gehler's Physik. Wörterbuch, viii. 373.—Mayo, Outlines of Human Physiology.—Sir C. Bell, Philos. Transact. 1832, pt. ii.—Malgaigne, Arch. Gén. de Méd. 25.—Willis, Transact. of Philos. Soc. of Cambridge, 1832.—Bishop, in Lond. and Edinb. Philos. Magaz. 1836.—Lehfeldt, Diss. de Vocis Formatione, Berol. 1835. On the voice of birds, see Cuvier, Anat. Comparée; and Savart. Froriep's Not. 331, 332. The American reader is referred more especially to the valuable work of Dr. James Rush, entitled Physiology of the Human Voice—Philadelphia, 2d edition.

[†] "Wind-chests" are the reservoirs of air in the organ, whence the wind is distributed to the pipes, when the keys or pedals are pressed down.

roid cartilage towards the cricoid cartilage, by means of the crico-thyroid muscles, as well as by the retraction of the arytenoid cartilages, which are moved backwards by the posterior crico-arytenoid muscles, at the same time that they are approximated to each other by the musculi arytenoidei. The effect of these movements of the thyroid and arytenoid cartilages is, as we have said, to make tense the vocal cords, either by the depression of the thyroid cartilage, the arytenoid cartilages having been previously fixed by their muscles, or by the retraction of the latter, after a fixed point has been obtained by the movement of the former. The length of the fissure of the glottis depends on the degree to which the cords are thus stretched. The aperture of the glottis is narrowed by the approximation of the arytenoid cartilages, which is effected by the musculi arytenoidei; it is dilated by means of the musculi crico-arytenoidei postici, which draw the arytenoid cartilages asunder. The vocal cords, by virtue of their elasticity, are capable of being thrown into regular vibrations, after the manner of membranes extended longitudinally from two extremities. Their elasticity is due to the elastic tissue which composes them, and which is also found in many other parts of the body (see page 206).

The vocal cords are not, however, the only parts of the larynx composed of elastic tissue. The ligamentum hyo-thyroideum and the ligamentum crico-thyroideum medium have been long known as yellow elastic ligaments. The last-named ligament must by its elasticity, and quite independently of any action of the crico-thyroid muscle, keep the corresponding borders of the cricoid and thyroid cartilages approximated to each other; and will therefore offer some resistance to the movement of the arytenoid cartilages backwards in the act of producing tension of the vocal cords, a certain degree of which will be produced by the elasticity of this ligament alone when the arytenoid cartilages are fixed by their muscles. A much wider distribution still of the elastic tissue in the larynx has been pointed out by M. Lauth.* The principal portion of the elastic tissue arises, according to M. Lauth, from the lower half of the angle of the thyroid cartilage between the insertions of the thyro-arytenoidei muscles. Thence the fibres radiate downwards, obliquely backwards, and even somewhat upwards, forming a continuous membrane, which is attached to the entire upper border of the cricoid cartilage, except at the situation of the arytenoid cartilages, where the fibres become connected with the anterior angle of the basis of those cartilages and with their anterior border. This radiating elastic membrane has three accessory fasciculi; one, which passes downwards, is the crico-thyroid ligament; the other two are the inferior thyro-arytenoid ligaments, or vocal cords. This elastic membrane forms also the superior ligaments of the glottis, which are connected with the inferior or true vocal cords by an extremely thin expansion of elastic tissue covering the ventricle of the larynx. The hyo-thyroid ligament also is elastic; and the same tissue exists likewise in the thyro-epiglottic, hyo-epiglottic, and glosso-epiglottic ligaments. If we add to these parts the elastic longitudinal fibres in the membranous part of the trachea and bronchi, we shall have an idea of the great extent of the tissues susceptible of consensual vibration and resonance in the parts surrounding the organ of voice.

The next point to be considered is the variety of forms which the aperture of the glottis is capable of assuming, and which it really assumes at the time of emitting sound. According to M. Lauth's researches, the glottis is able to take the following different forms. In the passive state, when emitting no sound, the aperture of the glottis is lance-shaped; it dilates somewhat, as is already known, during inspiration, and becomes narrowed again during expiration. The lateral boundaries of the aperture are, posteriorly, the inner surface and anterior process of the base of the arytenoid cartilages; anteriorly, and in the greater extent, the vocal cords, which are connected posteriorly to the above-mentioned anterior process of the basis of the arytenoid cartilages. The whole length of the aperture of the glottis when open is eleven lines, of which the posterior part between the arytenoid cartilages and their anterior process measures four, the anterior part between the vocal cords seven lines. When dilated to its full extent (by the musc. crico-arytenoidei postici), the aperture of the glottis has the form of a lozenge, of which the posterior angle is truncated. The lateral angles correspond to the anterior processes of the base of the arytenoid cartilages, which may be separated from each other to the distance of 5½ lines. In the contracted state, the rima glottidis may have either of three forms. The anterior processes of the base of the arytenoid cartilages may be approximated to each other through the agency of the lateral crico-arytenoid muscles, and by coming into contact may divide the fissure of the glottis into two parts; or the rima, though narrowed, may remain open in its whole length; or, lastly, the posterior part of the rima may be quite closed by the approximation of the arytenoid cartilages themselves, together with their anterior processes, to which the chordæ vocales are attached. The movement of the arytenoid cartilages, which produces this last form, is effected by the united action of the proper arytenoid muscles and of the lateral crico-arytenoid. The rima glottidis is here confined to the space between the sharp borders formed by the elastic vocal cords; it comes to a point both anteriorly and posteriorly; its length and breadth vary here very much, according as the vocal cords are stretched or not. The relaxation and shortening of the vocal cords are effected by the thyro-arytenoid muscles, which also are able to diminish the transverse diameter of the space above and below the vocal cords.

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* Mém. de l'Acad. Roy. de Méd. 1835.—Müller's Arch. 1836.—Jahresbericht, p. clvii.

The form of the rima glottidis in the human subject during life, at the moment of the emission of sound, is not at present very accurately known; but that it becomes narrowed is certain. The anterior portion of the aperture,—that bounded by elastic and sharp borders,—being alone susceptible of sonorous vibration from the action of the current of air, the posterior part of the opening, which cannot contribute to the original production of sound, can only by considerably increasing the area of the opening disturb the action of the air on the other part. M. Mayo (*Outlines of Physiol.* 1837, p. 371,) has made some observations on the movements of the glottis in the human subject during life. A man in an attempt to commit suicide divided the larynx immediately above the chordæ vocales: in consequence of the oblique direction of the wound the vocal cord and arytenoid cartilage of one side were wounded. During undisturbed respiration, the form of the aperture of the glottis was triangular. As soon as a sound was uttered, the chordæ vocales became almost parallel, and the rima glottidis took a linear form. It would appear from the figure that the posterior part of the aperture was not closed. In another patient the incision passed into the pharynx above the thyroid cartilage, rendering the upper part of the arytenoid cartilages visible. During the emission of sound the arytenoid cartilages kept the same position as when the glottis was closed. Kempelen (*Mechanismus d. Menschlich. Sprache.* Wien. 1791, p. 81,) has stated, that the glottis, to produce sound, must be approximated to within $\frac{1}{12}$th, or at most $\frac{1}{10}$th, of its diameter; and Rudolphi (*Physiologie*, ii. I. 370,) confirms this statement, from the observation of the parts in a man whose pharynx was by the absence of the nose laid so open to view that the opening and closing of the glottis could be readily seen.

M. Magendie excludes from the glottis the space between the arytenoid cartilages, which he has found in experiments on animals to be closely applied to each other during the emission of sound. Malgaigne has made the same observation. This may possibly be generally the case; and sounds cannot be readily elicited from the human larynx removed from the body, when the posterior portion of the glottis is not closed. Nevertheless it is not, according to my experiments, absolutely necessary; I have, in some rare cases, been able to produce a sound artificially, when the chordæ vocales were made somewhat tense and the aperture of the glottis narrowed, though open in its whole length.

B. *Of the modulation of the voice, and the causes on which it depends.*—Experiments on living animals have hitherto afforded few results calculated to elucidate the physiology of the human voice, notwithstanding the labours of MM. Magendie and Malgaigne, which are in a certain measure valuable. M. Magendie laid bare the glottis in a dog by means of an incision between the thyroid cartilage and os hyoides; he then observed that the vocal cords, during the utterance of deep notes, vibrated in their entire length, but that the portion of the rima glottidis which lies between the arytenoid cartilages was closed. During the utterance of very high notes, the vibrations were perceptible only in the most posterior part of the vocal cords, and the air escaped only through that part of the rima glottidis. It is difficult to understand how the closing of the anterior part of the glottis could be effected. Such a change in the glottis, causing the air to be transmitted only through the posterior part, cannot be imitated in the human larynx; while, on the contrary, it is not difficult to shorten the fissure of the glottis at its posterior part by approximating the anterior processes of the arytenoid cartilages to which the vocal cords are attached, the tension of these cords still remaining the same. Careful experiments on the human larynx itself, after its removal from the body, offer the best prospect of useful results.

Experiments on the separated larynx are, in first attempts, attended with extreme difficulty; all the parts are movable, and it is not at first apparent how the uniform tension and the uniform fixed position of the cartilages, so necessary for attaining any degree of accuracy in the experiments, can be given; and at the same time how the position once given can be made capable of alteration as the experiment may require. With a little contrivance, however, these objects can be accomplished. The first thing to be done is to obtain a fixed point in the larynx.

According to the result of experiments made in this way, the following will be the mode of production of the notes of the natural voice: —The vocal ligaments vibrate in their entire breadth, and with them the surrounding membranes and the thyro-arytenoid muscles. For the deepest notes the vocal ligaments are much relaxed by the approximation of the thyroid to the arytenoid cartilages. The lips of the glottis are, in this state of the larynx, not only quite devoid of tension; they are, when at rest, even wrinkled and plicated; but they become stretched by the current of air, and thus acquire the degree of tension necessary for vibration. From the deepest note thus produced the vocal sounds may be raised about an octave by allowing the vocal cords to have the slight degree of tension which the elastic crico-thyroid ligament can give them by drawing the thyroid cartilage towards the cricoid. The medium state, in which the cords are neither relaxed and wrinkled nor stretched, is the condition for the middle notes of the natural register, those which are most easily produced. (The ordinary tones of the voice in speaking are intermediate between these and the deep bass notes.) The higher notes are produced, and the corresponding falsetto tones avoided, by the lateral compression of the vocal cords, and by the narrowing of the space beneath them (the *aditus glottidis inferior*) by means of the thyro-arytenoid muscles, and further by increasing the force of the current of air. The muscular tension given to the lips of the glottis by the muscles above-mentioned must also be taken into account as contributing to the production of the notes of the natural register.

The falsetto notes are produced by the vibration of the inner portion or border of the vocal ligaments; their variation as to height or sharpness being effected by variation of the tension of the ligaments.*

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* To the above account of the conditions of the glottis and vocal cords necessary for the production of the different sounds of the voice, we may here append some

The observations which have been made prove clearly that neither the epiglottis, the superior ligaments of the glottis, the ventricles of the larynx, nor, in fact, any of the parts in front of the vocal cords, are necessary for the production either of the notes of the natural voice or of the falsetto notes.

The notes which are easily elicited from the *female larynx* are generally higher than those from the *male larynx*, though by complete relaxation and approximation of the vocal cords the female larynx can be made to yield deep tones. The principal cause of this is, that the vocal cords are in general much shorter in the female larynx; although the smaller size of the cavity of the larynx, and the less thickness of its walls, affording less means of resonance necessary for the low notes, have also a great influence. On the same principles we must explain different kinds of male voices,

observations on the same subject by several English physiologists. A very interesting paper by Mr. Willis, in the Transactions of the Cambridge Philosophical Society, 1832, (read May 1829,) contains some original views as to the position of the lips of the glottis during the production of voice. He attributes the different notes of the human voice to different degrees of tension of the vocal ligaments, since laminæ of leather, and, still better, caoutchouc, will, he shows, yield a variety of notes according to the degree of tension given them. But it is not tension alone, he argues, which enables the lips of the glottis to produce sounds. For as the size of the space between the thyroid and cricoid cartilages, felt externally, indicates the tension of the vocal ligaments,—being small when they are tense and high notes produced, and large when the ligaments are relaxed for the production of bass notes,—and as the medium size of this space, proper for the production of intermediate notes, does not differ from that which it has in the state of rest, when no voice is uttered, he infers that in that state the ligaments possess the tension required for the average pitch of speech, but have not the necessary parallel position. That the production of voice does not depend on diminishing the size of the aperture of the glottis he thinks certain, "because we can make the aperture of the passage pass through all degrees of contraction up to absolute closing during the expiration of the breath, without producing any sound, except the usual rushing noise of a forcible current of air passing through a narrow aperture." Mr. Willis attributes to the thyro-arytenoid muscles the office of placing the arytenoid cartilages and the lips of the glottis in the vocalising position.

Mr. Mayo has observed, in cases of wound of the pharynx, (as is stated in the text at page 691,) that the edges of the glottis are in contact during the utterance of vocal sounds; and this state of the glottis, together with a certain degree of tension, he believes to be the condition for vocalisation. The vocalising position pointed out by Mr. Willis, he conceives to be the necessary result of the vocal ligaments being on the stretch.—*Mayo's Physiology*, Ed. 4th, p. 370.

Mr. Bishop states, as the results of experiments on the larynx after death, "that, in order to produce any sounds whatever, it was requisite to close the chink of the glottis by bringing the edges of the vocal ligaments into immediate contact, when, by straining them tolerably tight, the sounds became loud and distinct." He also remarked, "that when the gravest tones were uttered, the ligaments vibrated throughout their whole length; and that, as the tones became more acute, a proportionally smaller extent of the ligaments was thrown into vibration." This observation accords with those of M. Magendie in experiments on living dogs (see page 691). "During the production of the most acute tones," Mr. Bishop says, "the tension of the vocal ligaments was but slightly increased, and the greatest possible tension was insufficient to produce acute tones, whilst these ligaments vibrated throughout their whole length." The latter observation is opposed to the results of Professor Müller's experiments. Mr. Bishop ascribes to the thyro-arytenoid muscle the power, not only of rotating the lips of the glottis into the vocalising disposition described by Mr. Willis, but also of forcing them into contact with each other during its contraction; and to the thyro-arytenoid and crico-thyroid muscles the power of so affecting the vocal cords "that a portion of them only is rendered susceptible of vibration."—London and Edin. Philos. Mag. 1836.—*Translator.*

the bass and tenor; and of female voices, the alto and soprano. The male voice is, it is true, capable of being raised to high notes by great tension of the cords, but the tones thus produced are of the falsetto character; notes of the same height can be produced with ease by the shorter vocal cords of the female larynx with less tension. Moreover, there must be a limit to the tension of the male chordæ vocales, on account of muscles being able to shorten themselves by contraction only to a certain extent; the maximum of shortening of which they are susceptible is, according to M. Schwann, only about one-third of their length. The means of rendering tense the vocal ligaments are somewhat greater than this calculation would indicate, since the vocal cords can be acted on by muscles both before and behind; and the cartilages to which the cords are attached are capable of a lever-like movement. Still there must be a limit to the raising of the pitch of the voice attained in this way. A still higher but feeble note may be accidentally produced, while the vocal cords are tense, by their coming into contact with each other at some point, causing a division of them into their aliquot parts.

I have endeavoured to ascertain by measurement the relative length of the vocal cords in the male and female larynx. The following table shows the results which I have obtained in several experiments:

	Men past puberty.						Women past puberty.			Boy of 14 years.
Length of the vocal cords at the greatest degree of tension,	21	21	25	26	23	23	16	15	16	14·5
Length of the vocal cords in the state of repose,	18	16	—	21	19	—	12	12	14	10·5

	Male larynx.	Female larynx.
Mean length of the vocal cords in the state of repose, - - - - - -	$18\frac{1}{4}$	$12\frac{2}{3}$
Mean length of the vocal cords in the state of greatest tension, - - - - -	$23\frac{1}{6}$	$15\frac{2}{3}$

The cyphers indicate the number of millimetres.* The relative length of the vocal cords in the male and in the female larynx would appear from these measurements to be as three to two, both in the extended and the unextended state. The degree to which the cords can be extended beyond their ordinary length is, in the male larynx, somewhat less than five millim.; in the female, three millim. The vocal cords alone, and not the whole length of the aperture of the glottis, extending posteriorly between the arytenoid cartilages, were measured. A small part of the vocal ligament extends farther back than the extreme point of the anterior process of the arytenoid cartilage, being attached to the upper border of this process towards the anterior edge of the cartilage; this portion of the ligament was included in the measurements.†

If the air be drawn in through the glottis instead of forced out, the tension of the vocal cords remaining the same, no vocal sound is generally produced, but sometimes a deeper rustling sound was heard. Touching the outer part of the ligaments of the glottis, so as to stop the vibrations at that part, raises the pitch of the sounds.

Influence of the vocal tube.—The length of the tube prefixed to the vibrating tongues, which has so marked an influence in modifying the height of the notes produced by tongues of caoutchouc or even of arterial tissue, appears from my experiments to have, contrary to M. Magendie's opinion, founded on the analogy of the organ of voice with the reed-pipes of M. Grenié, no perceptible effect on the pitch of the notes yielded by the human larynx. In many cases the variation of the length of the prefixed tube seemed to have no influence at all on the note produced; in other instances the elongation of the tube lowered the note a semitone, very rarely an entire tone, when the force of the blast was perfectly uniform. I am inclined, therefore, to deny any power of modifying the height of the notes to the slight variation of length which the trachea can undergo.

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* A millimetre is 0·03937, or about $\frac{1}{25}$ of an English inch.

† Admeasurements of the vocal cords of the larynx in the tense and lax condition, in bass, tenor, contr'alto, and soprano singers, and also in eunnchs, after death, would be of great interest in a physiological point of view; but the same parts should be measured in other individuals at the same time, that the grounds of the comparison may be the same, for if the vocal cords be measured from their anterior extremity only, as far as the point of the anterior process of the arytenoid cartilage, the length indicated will be less than when they are measured in the manner above described.

The partly membranous nature of the trachea has no perceptible influence on the sounds produced by the vocal cords; the note produced by blowing through the trachea was the same as when a wooden tube of the same diameter was used. In this respect reed-instruments with membranous tongues differ remarkably from flute-pipes with merely a vibrating column of air. In the latter instruments the reciprocal vibrations of the membranous walls of the tube influence so much the primary vibrations of the column of air, that, according to the observation of M. Savart, (*Froriep's Not.* 332, p. 21,) who discovered this circumstance, a pipe of moist thin paper walls will lower the note an entire octave below that which a tube of solid parietes of the same length would yield.

The circumstance of the vocal tube in front of the vocal cords being double, consisting of the oral and nasal canals, seems to have no other effect on the height of the notes than a simple tube; but it causes their character to be altered by the resonance. I attached to the short anterior tube of an artificial larynx with caoutchouc tongues a bifurcated tube; the result was no raising of the notes, but they were rendered more sonorous.

The *epiglottis*, by being pressed down so as to cover the superior cavity of the larynx, serves to render the notes deeper in tone, and at the same time somewhat duller, just as covering the end of a short tube placed in front of caoutchouc tongues lowers the tone. In uttering very deep notes during life, we evidently employ the epiglottis in this way; at least, such seems to be the object of the retraction and depression of the tongue, while we press down the head in front, in endeavouring to produce very deep notes. In no other respect does the epiglottis appear to have any effect in modifying the vocal sounds. The epiglottis can be felt, by the finger passed in at the side of the mouth, to maintain the same position during the utterance of musical notes, whether they be of the falsetto character or those of the natural voice.

The *arches of the palate and the uvula* become contracted during the formation of the higher notes, as was first observed by Fabricius ab Aquapendente, and more recently by Mayer, Bennati, and Dzondi. But the contraction of the isthmus of the fauces is the same for a note of given height, whether it be falsetto or not; and in either case the arches of the palate may be touched with the finger, without the note being altered. This completely refutes the opinion of Bennati, that the falsetto tone is wholly or in part due to the action of the palatine arches.

The approximation of the palatine arches, and retraction of the uvula, in the production of the higher notes, seems to be merely the result of involuntary associate nervous action, caused by the voluntarily increased exertion of the muscles of the larynx. If the palatine arches contribute at all to the production of the higher notes of the natural voice and the falsetto register, it can only be by their increased tension strengthening the resonance.

According to the theory of reed-instruments, narrowing of the *upper part of the larynx* immediately in front of the vibrating tongues or vocal cords ought to raise the notes in some degree: but this cannot be proved experimentally; for, in a larynx removed from the body, the upper part of the cavity cannot be compressed without, in some measure, acting on the vocal cords. Simple narrowing has no perceptible influence. The office of the *ventricles of the larynx* is evidently, as M. Malgaigne, Sir C. Bell, and others have remarked, merely to afford a free space for the vibrations of the lips of the glottis. M. Malgaigne compares them to the cavity at the commencement of the mouth-piece of trumpets, which allows the free vibration of the lips.

C. *Theories of the voice.*—The general conclusion which we must draw from the results of the experiments on the artificial larynx with membranous tongues, as well as from those afforded by the experiments on the natural larynx removed from the body, which, in all essential points, agree with the former, is that *the human organ of voice is a reed-instrument with a double membranous tongue.* This opinion has been previously held by several cultivators of natural philosophy, as MM. Biot, Cagniard la Tour, and Muncke; by writers on the theory of music, as Gottfr. Weber; and by some physiologists, as MM. Magendie, Malgaigne, and others.

The experiments of Ferrein on the sounds to be obtained from the larynx in the dead body, by which he showed that the note varied according to the length and tension of the vocal cords, have, as early as the year 1741, (*Mém. de l'Acad. d. Sc.*) afforded a sound basis for this theory.

According to M. Savart, the air in the ventricles of the larynx between the superior or false, and inferior or true ligaments, is really the source of the sound; the organ of voice being compared by this philosopher to the bird-call or hunter's whistle. The theory of M. Savart is rendered quite untenable by the fact of the superior ligaments of the glottis being entirely absent in some mammalia, namely, in the ruminantia.

The vocal cords were likened by Ferrein to vibrating strings, and to a certain extent correctly; but the comparison is in other points inaccurate. Ferrein's experiments, by which he demonstrated the resemblance of the vocal cords to vibrating strings, are among the best that have ever been instituted. He showed that the vocal cords sound, according to analogous laws with those of strings which are thrown into sonorous vibrations by currents of air, and that the notes produced are in no respect altered by difference in width of the aperture of the glottis. From half the length of the vocal cords he obtained the octave of the fundamental note; from two-thirds, the fifth. Lastly, he found that a change in the length of the vocal cords to the extent of from two to three lines was sufficient to produce all the notes of various pitch (the change in tension here supplying what is effected by change in the length of the cords when the tension remains the same).

In one respect, however, the vocal cords differ from strings; and this point of distinction is important enough to give to them, with other membranous tongues a special place among musical instruments. When strings are more strongly struck, deeper notes are produced; the note given out by a membranous tongue is, on the contrary, raised by a stronger blast the extent of one, two, or more semitones; and if the tongues be of moist nature, as are the vocal cords and bands of arterial tissue, even many semitones.

There are several physiologists, among them Dodart and Liscovius, who ascribe the modulation of the voice to the varying size of the fissure between the lips of the glottis, and to the vibration of the air produced at that part.

The influence of increasing the force of the blast in raising the pitch of the notes was correctly observed by Liscovius and Lehfeldt. A point of especial importance in reference to the theory of the production of the notes of the natural register and the falsetto notes,—namely, that for the former the entire vocal cord vibrates, and for the latter only its border, as well as the fact that the falsetto note is, *cæteris paribus*, higher,—was first discovered by Lehfeldt.*

D. *Of Singing.*—There are three different kinds of sequence of the notes which the organ of voice is capable of producing. The first is the monotonous, in which the notes succeeding each other have all nearly the same pitch, as in ordinary speaking; the variety of the sounds of speech being owing to articulation in the mouth; in speaking, however, occasional syllables generally receive a higher intonation for the sake of accent. In poetry there is rhythm in addition to the accent, but the modulation of music is wanting. The second mode of sequence is the successive transition from high to low notes, and *vice versâ*, without intervals; such as is heard in the sounds, which, as expressions of passion, accompany crying in men, and also in the howling and whining of dogs. This succession of dissonant sounds, in which the musical intervals are not observed, often occurs in nature, as in the howling of the wind; and may be produced on instruments,—for instance, by diminishing or increasing the tension of a string while it is being sounded, or by blowing with gradually increased force into a short pipe closed at one extremity. A membranous tongue is capable of the same succession of notes, and the same is the case with the vocal cords. The dissonant succession of rising and falling notes in howling must be produced partly by increase and diminution of the force of the current of breath, and partly by gradual alteration of the degree of tension of the vocal cords. The third mode of sequence of the vocal sounds is the musical, in which each sound has the requisite number of vibrations, and the number of vibrations in the successive sounds have that relative proportion which characterises the notes of the musical scale. Music has a rhythm in common with poetry.

1. *Compass of the voice.*—The compass of the voice in different individuals comprehends one, two, or three octaves; in singers,—that is, in persons capable of singing,—it extends to two or three octaves. But the male and female voices commence and end at different points of the scale.

2. *Varieties of voice in different individuals.*—The principal difference between the male and the female voice is in their pitch; but they are also distinguished by their tone,—the male voice is not so soft. But the voice presents other varieties besides the male and female; there are two kinds of male voice, the bass and tenor, and two kinds of female voice, the contr'alto and soprano, all differing from each other in tone. The bass voice usually reaches lower than the tenor, and its strength lies in the low notes; while the tenor voice extends higher than the bass. The essential difference between the bass and tenor voices, and between the contr'alto and soprano, consists in their tone or "timbre," [quality] which distinguishes them even when they are singing the same note.

The different pitch of the male and the female voice depends on the different length of the vocal cords in the two sexes; their relative length in men and women being as three to two. The difference of the two voices in tone or "timbre" is owing to the different nature and form of the resounding walls, which in the male larynx are much more extensive, and form a much more acute angle anteriorly.

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* Of previous writers, Ferrcin, Liscovius, and Lehfeldt, have contributed most to the elucidation of the theory of the voice. A very good account of the opinion of the older writers, with original reflections, is contained in Lehfeldt's dissertation, "De vocis formatione." Berol. 1835. A complete review of later theories and observations will be found in Hensinger's edition of Magendie's Physiology.

The larynx of boys resembles the female larynx; their vocal cords before puberty have not two-thirds the length which they acquire at that period. The angle of the thyroid cartilage is as little prominent as in the female larynx. Boys' voices are alto and soprano; but, after the larynx has undergone the change produced during the period of development at puberty (between the fourteenth and the fifteenth year,) they become immediately bass or tenor. While the change of form is taking place, the voice is imperfect, frequently hoarse and crowing, and is unfitted for singing until the new tones are brought under command by practice. In eunuchs, who have been deprived of the testes before puberty, the voice does not undergo the ordinary change.

3. *Varieties of voice in one and the same individual.—The natural and falsetto voices.*—Most persons, particularly men, besides that their voice belongs more or less to one of the varieties already described, have the power, if at all capable of singing, of modulating through a double series of notes of different character. These are the notes of the natural voice, or chest-notes (*note di pettò*), and the falsetto notes (*note di testa*). The natural voice is fuller, and excites a distinct sensation of much stronger vibration and resonance, than the falsetto voice, which has more a humming character.

4. *Differences of the voice as to tone or quality.*—Each individual has a peculiar tone of voice dependent on the form of the air-passages and of their lining membranes, and on their resonance: hence, many persons, by altering the form of their vocal organs, can imitate the various tones of voice of other individuals. The *nasal "timbre"* is a peculiar quality of voice dependent on a similar cause. The nasal tone may be given to the voice in two ways. 1. When the external openings of the nares are closed the voice may retain its natural sound, or it may become nasal: in the former case the arches of the fauces remain open; in the latter they approach each other, and the larynx ascends much higher than when the voice has its natural character. Obstruction of the nostrils by mucus has the same effect as closing the anterior openings of the nares; but neither the one nor the other can alone give the nasal tone to the voice. When the nasal tone is produced in this first way, the cavity of the nostrils becomes a separate resounding chamber. 2. The nasal twang may also be given when the nostrils are open, the mouth being either open or closed. In this case likewise the larynx ascends considerably; the arches of the fauces contract; the dorsum of the tongue is approximated to the palate, or brought into contact with it; and the air merely passes between the narrowed arches of the fauces, and receives the resonance of the nasal cavities without that of the cavity of the mouth.

The voice of old people is deficient in tone, is unsteady, and more restricted in extent: the first defect is owing to the ossification of the cartilages of the larynx and altered condition of the vocal cords: the want of steadiness arises from the loss of nervous command over the muscles; the result of which is here, as in other parts, a tremulous motion. These two causes combined render the voice of old people void of tone, unsteady, bleating, and weak.

5. *Strength of the voice.*—This depends partly on the degree of capability of vibration of the vocal cords; and partly on the fitness of the membranes and cartilages of the larynx, of the parietes of the thorax, lungs, and cavities of the mouth, nostrils, and communicating sinuses, for resonance. The capability of vibration of the vocal cords is diminished or destroyed by inflammation and suppuration of the mucous membrane of the larynx, by profuse secretion of mucus, by œdema glottidis, &c.

6. *Increase and diminution of the intensity of the vocal sound.*—The intensity or loudness of a given note emitted by the larynx cannot be rendered greater by merely increasing the force of the current of air through the glottis; for increase of the force of the current of air, *cæteris paribus*, raises the pitch both of the natural and the falsetto notes.

Since the human organ of voice possesses the power of increasing the intensity of a note from the faintest "piano" to "fortissimo" without its pitch being altered, there must be some other means of compensating the tendency of the vocal cords to emit a higher note when the force of the current of air is increased. This means evidently consists in modifying the tension of the vocal cords. When a note is rendered more intense, the vocal cords must be relaxed by remission of the muscular action in proportion as the force of the current of the breath through the glottis is increased. When a note is rendered fainter, the reverse of this must occur.

7. *Perfectness of the notes.*—The dissonance of the voice after long singing may easily be accounted for in part by the slight changes which the vocal cords have undergone in consequence of repeated tension; and in a greater degree by the fatigue of the muscles, which at length cease to obey the will perfectly, and execute inappropriate movements. An habitual dissonance of the voice, or inability to sing in tune, depends partly on defect of the sense of hearing, and partly on the difficulty of observing the uniform "temperament" of our musical scales. Temperament is usually already obtained in musical instruments by tuning; the singer must attend to it at each note.

We must conclude our observations on the human voice with some remarks on the artificial construction of a vocal organ. No musical instrument can be in all respects compared to the organ of voice; for even the organs and pianos, of which the compass is so great, are defective in other respects. Some musical instruments, as the simple flute-pipes, are not susceptible of an increase of the intensity of the notes from piano to forte; in others the notes cannot be prolonged, namely, in all those instruments in which the sounds are produced by striking strings. The organ has two registers of notes,—those of the flute-pipes and the reed-pipes; and in this respect it resembles the human voice, which has the natural register and the falsetto: but no instrument combines like the human organ of voice all these advantages. Although the organ of voice belongs to the class of reed-instruments; and though these reeds, when combined with a system of compensating pipes, are (with the violin) the most perfect of all instruments; yet still the vocal organ is more perfect in being capable of giving with one tube all the notes and all the possible variations of the scale, while in the most complete instrument constructed of reed-pipes each note requires a special pipe. The artificial construction of a vocal organ would, in some measure, be attained, if with a reed-pipe an apparatus, of not too difficult management, for regulating the tension of elastic tongues in the reed, could be combined; but the tones of such an instrument, in which dry elastic bands only could be permanently used, would not resemble the soft full tones given out by the moist, animal, elastic tissue, and there would always be great difficulty in managing such an instrument.

2. *Of musical sounds formed in the mouth.*

We do not speak here of all the noises which may be produced in the mouth, but only of those which have a musical quality or tone. Both at the anterior and at the posterior part of the oral cavity musical sounds may be produced on the principle of the sounds of reed-instruments; such are the snoring and other sounds given out by the arches of the fauces in vibrating, and the sounds produced by pressing air between the lips which are thrown into distinct vibrations; the notes thus produced being higher in pitch, the greater the tension of the lips.

Another kind of musical sound produced in the mouth is "*whistling*,"[*] in which the air is the source of the sound. It is easy to convince one's-self that the sound in whistling is not owing to vibration of the lips; for they may be touched, covered, or even a disk of cork with a central hole held between them, as Cagniard la Tour showed, and yet the same sounds will be produced.

CHAPTER II.

OF SPEECH.[†]

Besides the musical tones formed in the larynx, a great number of other sounds can be produced in the vocal tube between the glottis and the external apertures of the air-passages, the combination of which into different groups to designate objects, properties, actions, &c. constitutes language. The languages do not employ all the sounds which can be produced in this manner, the combination of some with others being often difficult. Those sounds which are easy of combination enter for the most part into the formation of the greater number of languages. Each language contains a certain number of such sounds, but in no one are all brought together. On the contrary, different languages are characterised by the prevalence in them of certain classes of these sounds, while others are less frequent or altogether absent. It comes within the province of physiology to investigate the natural classification of the sounds of language. The attempts to form a natural system of the articulate sounds, instituted by grammarians, have been quite inadequate to the object, the principle of classification having been derived from properties which are not essential. The classification of the sounds of articulate speech, according to the organs by which they are formed,—for example, into the labial, dental, guttural, and lingual,—is faulty when carried farther than the distinction of the oral and nasal sounds; for sounds which are, according to physiological principles, in part quite different from each other, are thus classed together, and, moreover, for the formation of most sounds several parts of the mouth co-operate. The distinction of the mutes and liquids is in part founded on correct principles; but the application of these principles has been imperfect. Even the properties of the vowels, as contra-distinguished from the consonants, have not been properly estimated. Their essential character is usually considered to be that they are independent sounds, originally formed in the larynx, though modified in the mouth; while consonants are not formed in the larynx, and cannot be sounded perfectly unless conjoined with a vowel. The difference between vowels and consonants is, however, much less considerable than this; for all vowels, as well as the consonants, can be produced without a vocal tone, as in whispering; and, moreover, one whole class of consonants can, as we shall presently see, be uttered with a vocal sound as well as without this sound. The essential difference between vowels and consonants is of a very different nature. A main error in many of the attempts at classification of the articulate sounds has been the failing to pay sufficient attention to the circumstance of it being possible to form them without vocal tone, as in whispering; while to recognise the essential properties of the articulate sounds we must first examine them as they are produced in whispering, and then investigate which of them can also be uttered in a modified character conjoined with vocal tone. By this procedure we find two series of sounds: in one the sounds are mute, and cannot be uttered with a vocal tone; the sounds of the other series can be formed independently of voice, but are also capable of being uttered in conjunction with it. Another important character of some of the articulate sounds is that they are only of momentary duration, taking place during a sudden change in the conformation of the mouth, and are not capable of prolongation by a continued effusion of the breath ("*strepitus incontinuus explosivus*"); while others can be prolonged, *ad libitum*, as long as a particular disposition of the mouth and a constant expiration are maintained ("*strepitus continuus*").* All sounds of the first kind are insusceptible of combination with vocal tone ("intonation,") and are absolutely mute; nearly all the consonants of the second kind may be attended with "intonation." Peculiar modifications of the sounds are thus produced, but the absolutely mute consonants, with "*strepitus explosivus*" may by aspiration be completely changed to other sounds.

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[*] See Muncke in Gehler's Physikal. Wörterb. viii. p. 383; and Cagniard la Tour in Magendie's Journal de Physiol. t. x.

[†] The authors who may be consulted on the subject of speech are: J. Wallis, De loquelâ s. sonorum formatione, in C. Amman, Surdus loquens. Lugd. Bat. 1727.—Kratzenstein, Tentamen resolvendi problema ab Acad. Sc. Petrop. 1780; propos. Petrop. 4.—Kempelen, Mechanismus der Menschlichen Sprache nebst der Beschreibung seiner sprechenden Maschine. Wien, 1791, 8.—Reitter, Methodenbuch zum Unterricht für Taubstumme. Wein, 1828.—Rudolphi, Physiologie.—Chladni, in Gilbert's Ann. 1824, st. 2.—C. Mayer, in Meckel's Archiv. für Anat. u. Physiol. 1826.—R. Willis, in Poggendorf's Annal. xxiv. and Transact. of Philos. Soc. of Cambridge, vol. iii.—Heusinger, in his edition of Magendie's Physiology.—Purkinje, Badania w przedmiocie fizyologii mowy Ludzkiéj. Kraków, 1836, 8. (Forschungen über die Physiologie der Menschlichen Sprache. Krakaw, 1836.)

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* Kempelen, in his experiments on the artificial production of articulate sounds, observed, that the vowel sounds were distinct only when contrasted with each other;

A. *Mute sounds of the whisper.*

I. *Mute vowels.*—All the vowels with their nasal modifications can be expressed in a whisper without vocal tone. These mute vowel sounds differ, however, in some measure as to their mode of production from the consonants. All the mute consonants are formed in the vocal tube above the glottis, or in the cavity of the mouth or nose, by the mere rushing of the air between surfaces differently modified in disposition. But the sound of the vowels, even when mute, has its source in the glottis, though the vocal cords are not thrown into the vibrations necessary for the production of voice; and it seems to be produced by the passage of the current of air between the relaxed vocal cords. That the whispered vowels are formed at the glottis, and not in the mouth, any one may satisfy himself by experiments in his own person. The same sound can be produced in the larynx when the mouth is closed, the nostrils being open, and the utterance of all vocal tone avoided. This sound, when the mouth is open, is so modified by varied form of the oral cavity as to assume the character of the vowels *a, e, i, o, u.*

The oral canal or cavity of the mouth assumes the same form for the articulation of each of the mute vowels as for the corresponding vowel when vocalised; the only difference in the two cases lies in the kind of sound emitted by the larynx.

II. *Mute consonants with "strepitus æqualis s. continuus." Continuous sounds.*—All consonants of this class can be pronounced with an uninterrupted sound, which continues as long as the expiration can be prolonged; the disposition of the parts within the mouth remaining throughout as at the commencement of the formation of the sound. The consonants of this kind are *h, m, n, ng, f, ch* [as in the Scotch word "loch," or like the *gh* in the word "light," as pronounced by the Scotch] *sch* [equivalent to the English *sh,*] *s, r,* and *l.*

III. *Mute consonants with "strepitus explosivus." Explosive sounds.*—These are the Greek β, γ, δ, and their modifications, π, κ, τ. They are the explosive sounds of Amman.

The organs of speech engaged in the formation of these sounds undergo a sudden change of position during their production; the sound commences with the closing of the mouth, and terminates with the opening of it. Hence these consonants cannot be prolonged *ad libitum.* The sound ceases as soon as the mouth is opened.

1. Simple explosive sounds, *b, d, g* (the hard *g* or gamma).
2. Aspirate explosive sounds, *p, t, k.*

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and even in the natural voice, as Mr. Willis observes, "if any given vowel be prolonged by singing, it soon becomes impossible to distinguish what vowel it is." This is more remarkably the case with many of the continuous consonants than with the vowels."—*Translator.*

These are merely modifications of *b*, *d*, *g*, produced by a stronger aspiration during the opening of the previously closed passage of the mouth. (This explanation was given in my "Grundriss der Physiologie," in 1827.)

B. *The sounds of vocalised speech.*

In the vocalised speech some few consonants have still merely the character of whispered sounds, being incapable of combination with any vocal tone. Other consonants are in vocalised speech susceptible of two modes of pronunciation, the mute and the vocalised. The vowels have the vocal tone.

I. *Vowels.*—The disposition of the organs of speech is the same for the vocalised as for the mute pronunciation of the vowels; the vocal tone produced in the larynx by the vibrations of the vocal cords is modified in the throat, mouth, and oral opening into the different vowels. The proper diphthongs are combinations of two vowels. The English *i* in its long sound is the equivalent of the German diphthong *ei*, and seems to be really a combination of two sounds. The sound of *i* cannot, like a true vowel, be prolonged *ad libitum;* but appears rather to result from the transition from a peculiar murmur to the sound of *e*, just as the diphthong *oy* or *oi* results from the transition from broad *a* to *e*.

A peculiar murmuring sound accompanies several consonants, which does not resemble any of the vowels. This kind of intonation can be produced either with the mouth open or with it closed, the nasal passage being in the latter case open.

II. *Consonants which, in vocalised speech, are not accompanied with a vocal sound.*

1. The explosive *b*, *d*, *g* (*γ*), and their modifications *p*, *t*, *k*. It is quite impossible to combine the sounds of these consonants with an intonation of the voice. If it be attempted to pronounce them aloud, the intonation only follows them, and the result is the combination of the mute consonant with a vowel. .

2. The only continuous consonant which cannot be pronounced in combination with a vocal sound is the aspirate *h*. The aspiration of the *h* ceases immediately that the vocal cords are thrown into sonorous vibrations.

III. *Consonants which, in vocalised language, can be pronounced either as mute sounds or with vocal intonation.*—These are all of the class of continuous consonants; namely, *f*, the German *ch*, *sch* [the English *sh*, and French *che*], *s*, *r*, *l*, *m*, *n*, *ng*.

The different sounds and tones of language being dependent on certain physical conditions, are of course capable of imitation by artificial contrivances. Some are produced very easily in this manner, as *b*, which is heard when the sound of the voice is made to pass into a cylindrical tube, before which the hand is held and then withdrawn; the German *w* [*v*] may be formed in the same way if the tube be a pipe with membranous tongue. Experiments relative to the artificial production of the articulate sounds have been made by Kratzenstein, Kempelen, and Mr. R. Willis. They have succeeded in imitating a great part of the sounds used in speech. But these speaking-machines are always to a certain extent imperfect, since every simple and independent sound and consonant requires a special apparatus; and the combination of the different apparatus with a common tube for the supply of air, so as to form words, is exceedingly difficult. We cannot be surprised also at some birds, as the parrot and raven, being capable of uttering articulate sounds, since their mouth has the same general conformation with parts which can act as valves. The mode of articulating sounds is, without doubt, learnt by these birds in the same way as by the human infant. The different sounds are first produced without any order or proposed end; but, while thus produced, the movements necessary for the formation of each become impressed on the sensorium, and are therefore readily associated again when the sound which they are calculated to give rise to is heard.

C. *Ventriloquism.*—The peculiarity of the particular mode of speaking which is so called, has been supposed by some physiologists, as M. Magendie, to consist merely in the varied modification of the sounds produced in the larynx, in imitation of the modifications which voice ordinarily suffers from distance, &c.; by others it is imagined to depend on some common cause, which modifies all the tones uttered, for example, on the articulation taking place during inspiration. This last is the view generally taken of the cause of ventriloquism. It is certainly possible to articulate during inspiration, though with difficulty; and the sounds thus produced have some similarity with the tones of the voice of the ventriloquist. But, nevertheless, I regard the opinion in question as erroneous; for the sounds uttered by the ventriloquist can be perfectly imitated much more easily by another method, which I am convinced must be adopted by the ventriloquists themselves. The method to which I allude consists in inspiring deeply, so as to protrude the abdominal viscera by the descent of the diaphragm, and then speaking while the expiration is performed very slowly through a very narrow glottis by means of the lateral parietes of the thorax alone, the diaphragm maintaining its depressed position. The timbre which the voice has in speaking during an expiration thus performed is that peculiar to ventriloquism. Sounds may be thus uttered which resemble the voice of a person calling from a distance.

A great part of the art of the ventriloquist, for example, in imitating the voices, coming from particular directions, consists merely in deceiving other senses than hearing. We never distinguish very readily the direction in which sounds reach our ear; and, when our attention is directed to a particular point, our imagination is very apt to refer to that point whatever sounds we may hear.

D. *Defective speech.*—The proper exercise of the faculty of speech presupposes the possession of a normally-formed oral cavity as well as a good sense of hearing. Imperfections of speech arise from a want of either of these requisites. An opening in the palate renders the formation of some sounds impossible, and gives to the voice a nasal timbre; want of teeth also renders the speech imperfect.*

By want of command, or loss of power of the tongue, speech is rendered indistinct and unintelligible. This is observed as a temporary consequence of intoxication, and as a permanent result of paralysis of the ninth nerve.

The speech may, however, be imperfect also from the sounds not following each other as they ought to do, though the individual sounds be pronounced perfectly; such is stammering. It consists in a momentary inability to pronounce a consonant or vowel, or to connect it with the preceding sounds. This impediment may occur either at the commencement or in the middle of a word. In the latter case, the commencement of the word is often several times repeated; the part of the word thus repeated may end with a vowel, and the difficulty then consists in connecting with this the following consonant; or it may be merely the commencing consonant which is repeated, and with which the succeeding vowel cannot be combined. The repetition of the commencement of the word, as Schulthess rightly remarks, is not the essential condition of stammering; it is merely a new attempt at overcoming the impediment. If the consonant preceding the impediment be one of the explosive class, (*b*, *d*, *g*, and *p*, *t*, *k*,) which do not admit of a continuous pronunciation until the formation of the vowel is attained, it is more prone to be frequently repeated; thus, a person who stammers, says for "bitter," b-b-b-bitter. But if it be a continuous consonant, as *m*, *n*,

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* On defects in the formation of particular letters, see Kempelen and Schulthess, loc. cit.

ng, *f*, χ [the German and Scotch *ch*,] *sh*, *r*, *l*, or *s*, it is not necessarily repeated, because the sound of a continuous consonant can be prolonged *ad libitum*, until the vowel follows it; for example, in the word "laughing." It does, however, sometimes happen that the continuous consonant is repeated in such a case, and the word is pronounced l-l-l-l-laughing. Sometimes letters which do not belong to the word are involuntarily introduced.

Schulthess maintains that the stammering does not arise from any difficulty in the pronunciation of the consonants, but that the impediment attends the utterance of the vowels. This view is founded on good observations; but, though an improvement on the previous erroneous opinions, it goes further than facts justify, for the vowel is often formed while the following consonant cannot be combined with it. I knew a young man of distinguished mathematical attainments, who had previously stammered very badly, and in pronouncing his own name, was apt to say Te-tessot instead of Tessot. In many cases also the impediment attaches to the first consonant of a word; and here likewise the difficulty does not so much depend on the parts of the mouth which are engaged in articulation, as on the arrest of the passage of the air necessary for the pronunciation of a particular consonant, by the momentary closure of the glottis. This closure of the glottis, the importance of which has been particularly pointed out by Dr. Arnott,* occurs only in the attempt to articulate particular sounds, by involuntary association, the supply of air for the articulation of other sounds not being impeded; the syllable preceding the arrest of speech can, for example, be frequently repeated. The essential cause of the impediment is always situated in the glottis, whether it be that the vocal cords do not give the requisite sound when it is a vowel which is attempted to be formed, or that the passage of the air is arrested during the attempt at articulation in the mouth. In persons who stammer very badly, there are evident signs of the struggle at the glottis, afforded by the impediment to expiration and by the congestion of blood in the head and veins of the neck. The essential cause of stammering is, therefore, clearly an unnatural associate movement in the larynx by consent with the movements of the mouth, or articulate movements. When the struggles of stammering are violent, associate movements are observed also in the face. It is the same condition as that of a person who wishes to move one particular muscle of his face, but on account of association of nervous action, or defect of the power of insulating the nervous influence, cannot do it without distorting all his features.†

I agree entirely with Dr. Arnott and Schulthess in considering the immediate cause of stammering to be a spasmodic affection of the glottis. This affection consists in a momentary closure of the aperture, partly by the approximation of the arytenoid cartilages and partly by the pressure of the musculi thyro-arytenoidei, which are capable of pressing the ligaments of the glottis into contact with each other. It must be remembered as a principle that this momentary spasm depends entirely on a morbid association of the muscles of the larynx with the movements of the organs of articulation. The position of the mouth for the pronunciation of *b* is assumed, and the lips can be separated in the manner proper for the utterance of the sound; but when this is done, or ought to be done, the breath is wanting,—it is arrested at the larynx. The natural indication, therefore, for the prevention of stammering is to attempt to bring more under the command of the will the associations between the movements of articulation and the movements of the larynx. One method of fulfilling this indication is the singing of the words, in which the attention is directed more to the action of the larynx than in ordinary speaking. Persons who stammer pronounce better in singing than in mere speaking.

A too low position of the tongue in the mouth appears to favour stammering. The method of treatment practised by Mad. Leigh consisted in preventing this position of the tongue, and in raising its point towards the palate. The practice of placing bodies under the tongue, which was known to the ancients, tended to the same object.

The method proposed by Dr. Arnott for the cure of stammering, whatever may be the result of its practice, is, at all events, founded on a sound physiological view of the nature of the affection. "Had the edges of the glottis," says Dr. Arnott, "been visible, like the external lips of the mouth, the nature of stuttering would not so long have remained a mystery." The glottis is repeatedly closed in persons who stammer, and the cure of the affection must therefore be effected by conquering this morbid tendency to closure by voluntarily keeping it open as much as possible. For this purpose Dr. Arnott advises that the patient should connect all his words by an intonation of the voice continued between the different words, as is done by persons who speak with hesitation. This plan may afford some benefit, but cannot do everything; since the main impediment occurs in the middle of words themselves, and depends on the abnormal association of the movement of the larynx with certain movements of articulation. Were I called upon to advise a method of treatment in a case of stammering, I would recommend, in addition to Dr. Arnott's plan, the following procedure: I would let the patient practise himself in reading sentences in which all letters which cannot be pronounced with a vocal sound, namely the explosive consonants *b*, *d*, *g*, *p*, *t*, and *k*, were omitted, and only those consonants included which are susceptible of an accompanying intonation of the voice; and I would direct that all these letters should be pronounced with such a sound of the voice, and that their sound should be very much prolonged. By this means a mode of pronunciation would be attained in which the articulation would be constantly combined with vocalisation, and the glottis consequently never closed. When the stammerer had lông practised himself in keeping the glottis open without intermission, even between the words by Dr. Arnott's method, and in maintaining the glottis open during and after the pronunciation of every consonant capable of vocalisation and of the vowels, he might proceed to the mute and continuous consonant *h*, and the explosive sounds *g*, *d*, *b*, *k*, *t*, *p*. In such a plan of treatment, the patient himself would perceive the principle; while the ordinary method—that of Mad. Leigh—is mere groping in the dark, neither teacher nor pupil knowing the principle of the procedures. (See *Schulthess*, loc. cit. p. 166.)

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* Elements of Physics, vol. i.

† See the remarks on associate nervous action and associate movements, at pages 533 and 670.

There is a kind of defect of speech essentially different from stammering, consisting in a protracted intonation of the voice between words, or the introduction of a more or less prolonged *a* or *au*,—nasal vowel sounds, or peculiar vocal sounds modified by a jingling character between the words, which themselves are correctly pronounced; for example, I . . . a . . . have. It is like the prolonged vibration of a musical instrument beyond the required duration. These sounds form and facilitate the transition from one word to another, and they may frequently be produced as a means of transition; although they, in many instances, also arise from hesitation or want of readiness of the ideas. This mode of speaking sometimes attends stammering, probably because the impediment to the commencement of the next word is avoided by this transition of sounds.

The formation of perfect vocal tones presupposes the possession of the sense of hearing. It is only with the greatest labour that individuals born deaf can learn to utter a series of harsh sounds. The deaf and dumb owe their want of speech to their deafness: they can by great labour learn the movements of articulation by means of their sight; but their speech is never more than a series of harsh sounds, not adapted for human society, for they want the sense of hearing to regulate their articulation.

There is no nearer medium of connection between the faculties of speech and hearing than the brain, and it is not evident how nervous communications could be of service to either organ. The connection of the facial nerve with the lingual branch of the fifth can have no influence on speech or hearing; for the facial nerve has nothing to do with hearing; the lingual branch of the fifth nothing to do with speech. The nerve on which the movements of speech principally depend is the ninth nerve, which supplies all the muscles of the tongue; the facial also has some share in articulation, at all events as regards the movements of the lips. Both the last-named nerves are engaged in physiognomical expression, since the automatic movements of the features as well as speech disclose in different ways what is passing in the mind. Both nerves appear to arise from the same nervous centre,—the olivary body. (See *Retzius*, *Müller's Archiv*. 1836.)

BOOK VI.

OF THE SENSES.

PRELIMINARY CONSIDERATIONS.

The senses, by virtue of the peculiar properties of their several nerves, make us acquainted with the states of our own body, and they also inform us of the qualities and changes of external nature, as far as these give rise to changes in the condition of the nerves. Sensation is a property common to all the senses; but the kind, ("*modus*,") of sensation is different in each: thus we have the sensations of light, of sound, of taste, of smell, and of feeling or touch. By feeling, or touch, we understand the peculiar kind of sensation of which the ordinary sensitive nerves generally—as, the nervus trigeminus, vagus, glosso-pharyngeus, and the spinal nerves,—are susceptible; the sensations of itching; of pleasure and pain, of heat and cold, and those excited by the act of touch in its more limited sense, are varieties of this mode of sensation. That which through the medium of our senses is actually perceived by the sensorium, is indeed merely a property or change of condition of our nerves; but the imagination and reason are ready to interpret the modifications in the state of the nerves produced by external influences as properties of the external bodies themselves. This mode of regarding sensations has become so habitual in the case of the senses which are more rarely affected by internal causes, that it is only on reflection that we perceive it to be erroneous. In the case of the sense of feeling or touch, on the contrary, where the peculiar sensations of the nerves perceived by the sensorium are excited as frequently by internal as by external causes, it is easily conceived that the feeling of pain or pleasure, for example, is a condition of the nerves, and not a property of the things which excite it. This leads us to the consideration of some general laws, a knowledge of which is necessary before entering on the physiology of the separate senses.

I. In the first place, it must be kept in mind that *external agencies can give rise to no kind of sensation which cannot also be produced by internal causes, exciting changes in the condition of our nerves.*

In the case of the sense of touch, this is at once evident. The sensations of the nerves of touch (or common sensibility) are those of cold and heat, pain and pleasure, and innumerable modifications of these, which are neither painful nor pleasurable, but yet have the same kind of sensation as their element, though not in an extreme degree. All these sensations are constantly being produced by internal causes in all parts of our body endowed with sensitive nerves; they may also be excited by causes acting from without, but external agencies are not capable of adding any new element to their nature. The sensations of the nerves of touch are therefore states or qualities proper to themselves, and merely rendered manifest by exciting causes external or internal. The sensation of smell also may be perceived independently of the application of any odorous substance from without, the nerve of smell being thrown by an internal cause into the condition requisite for the production of the sensation. This perception of the sensation of odours without an external exciting cause, though not of frequent occurrence, has been many times observed in persons of an irritable nervous system; and the sense of taste is probably subject to the same affection, although it would always be difficult to determine whether the taste might not be owing to a change in the qualities of the saliva or mucus of the mouth; the sensation of nausea, however, which belongs to the sensations of taste, is certainly very often perceived as the result of a merely internal affection of the nerves. The sensations of the sense of vision, namely colour, light, and darkness, are also perceived independently of all external exciting cause. In the state of the most perfect freedom from excitement, the optic nerve has no other sensation than that of darkness. The excited condition of the nerve is manifested, even while the eyes are closed, by the appearance of light, or luminous flashes, which are mere sensations of the nerve, and not owing to the presence of any matter of light, and consequently are not capable of illuminating any surrounding objects. Every one is aware how common it is to see bright colours while the eyes are closed, particularly in the morning when the irritability of the nerves is still considerable. These phenomena are very frequent in children after waking from sleep. Through the sense of vision, therefore, we receive from external nature no impressions which we may not also experience from internal excitement of our nerves; and it is evident that a person blind from infancy in consequence of opacity of the transparent media of the eye, must have a perfect internal conception of light and colours, provided the retina and optic nerve be free from lesion. The prevalent notions with regard to the wonderful sensations supposed to be experienced by persons blind from birth when their sight is restored by operation, are exaggerated and incorrect. The elements of the sensation of vision, namely the sensations of light, colour, and darkness, must have been previously as well known to such persons as to those of whom the sight has always been perfect. If, moreover, we imagine a man to be from his birth surrounded merely by external objects destitute of all variety of colours, so that he could never receive the impressions of colours from without, it is evident that the sense of vision might nevertheless have been no less perfect in him than in other men; for light and colours are innate endowments of his nature, and require merely a stimulus to render them manifest.

The sensations of hearing also are excited as well by internal as by external causes; for, whenever the auditory nerve is in a state of excitement, the sensations peculiar to it, as the sounds of ringing, humming, &c. are perceived. It is by such sensations that the diseases of the auditory nerve manifest themselves; and, even in less grave transient affections of the nervous system, the sensations of humming and ringing in the ears afford evidence that the sense of hearing participates in the disturbance.

No further proof is wanting to show, that external influences give rise in our senses to no other sensations, than those which may be excited in the corresponding nerves by internal causes.

II. *The same internal cause excites in the different senses different sensations;—in each sense the sensations peculiar to it.*

One uniform internal cause acting on all the nerves of the senses in the same manner, is the accumulation of blood in the capillary vessels of the nerve, as in congestion and inflammation. This uniform cause excites in the retina, while the eyes are closed, the sensation of light and luminous flashes; in the auditory nerve, humming and ringing sounds; and in the nerves of feeling, the sensation of pain. In the same way, also, a narcotic substance introduced into the blood excites in the nerves of each sense peculiar symptoms; in the optic nerves the appearance of luminous sparks before the eyes; in the auditory nerves, "tinnitus aurium;" and in the common sensitive nerves the sensation of ants creeping over the surface.

III. *The same external cause also gives rise to different sensations in each sense, according to the special endowments of its nerve.*

The mechanical influence of a blow, concussion, or pressure excites, for example, in the eye the sensation of light and colours. It is well known that by exerting pressure upon the eye, when the eyelids are closed, we can give rise to the appearance of a luminous circle; by more gentle pressure the appearance of colours may be produced, and one colour may be made to change to another. Children, waking from sleep before daylight, frequently amuse themselves with these phenomena. The light thus produced has no existence external to the optic nerve, it is merely a sensation excited in it. However strongly we press upon the eye in the dark, so as to give rise to the appearance of luminous flashes, these flashes, being merely sensations, are incapable of illuminating external objects. Of this any one may easily convince himself by experiment. I have in repeated trials never been able, by means of these luminous flashes in the eye, to recognise in the dark the nearest objects, or to see them better than before; nor could another person, while I produced by pressure on my eye the appearance of brilliant flashes, perceive in it the slightest trace of real light. (See page 95.)

The supposed emission of light by the eyes of animals has been already discussed in the Prolegomena, page 95. It is not, *à priori*, contrary to known laws, to suppose that the nerves of animals may develope luminous matter; and since we have in the retina of the eye an opportunity which we have nowhere else, of observing a nerve through transparent media without inflicting any injury on the animal, it would be here that such a phenomenon would be best observed. The fact of light being developed by the retina and nerves, even were it proved by experiment, would not, however, influence the explanation of the appearance of light produced in the eye by internal causes.

A mechanical influence excites also peculiar sensations of the auditory nerve; at all events, it has become a common saying, "to give a person what will make his ears ring," or "what will make his eyes flash fire," or "what will make him feel;" so that the same cause, a blow, produces in the nerves of hearing, sight, and feeling, the different sensations proper to these senses. It has not become a part of common language that a blow shall be given which will excite the sense of smell, or of taste; nor would such sayings be correct;* yet mechanical irritation of the soft palate, of the epiglottis and root of the tongue, excites the sensation of nausea. The action of sonorous bodies on the organ of hearing is entirely mechanical. A sudden mechanical impulse of the air upon the organ of hearing produces the sensation of a report of different degrees of intensity according to the violence of the impulse, just as an impulse upon the organ of vision gives rise to the sensation of light. If the action of the mechanical cause on the organ of hearing be of continued duration, the sound is also continued; and when caused by a rapid succession of uniform impulses, or vibrations, it has a musical character. If we admit that the matter of light acts on bodies by mechanical oscillation, (the undulation theory,) we shall have another example of a mechanical influence, producing different effects on different senses. These undulations, which produce in the eye the sensation of light, have no such effect on other senses; but in the nerves of feeling they produce the sensation of warmth.†

The stimulus of electricity may serve as a second example, of a uniform cause giving rise in different nerves of sense to different sensations. A single pair of plates of different metals applied so as to include the eye within the circle, excites the sensation of a bright flash of light when the person experimented upon is in a dark room; and, even though the eye do not lie within the circle, if it be not distant from it,—as, for example, when one of the plates is applied to one of the eyelids, and the other to the interior of the mouth,—the same effect will be produced, owing to a part of the current of electricity being diverted to the eye. A more intense electric stimulus gives rise to more intense sensations of light. In the organ of hearing, electricity excites the sensation of sound. Volta states that, while his ears were included between the poles of a battery of forty pairs of plates, he heard a hissing and pulsatory sound, which continued as long as the circle was closed. (*Philos. Transact.* 1800, p. 427.) Ritter perceived a sound like that of the fiddle G at the moment of the closure of the galvanic circle.

The electricity of friction, developed by the electrical machine, excites in the olfactory nerves the odour of phosphorus. The application of plates of different metals to the tongue, gives rise to an acid or a saline taste, according to the length of the plates which are applied one above, and the other beneath the tongue. The facts detailed with regard to the other senses are sufficient to show that these latter phenomena cannot be attributed to decomposition of the salts of the saliva.

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* The influence of mechanical agency in exciting the nerve of taste to its peculiar reaction may be made quite perceptible; but the stimulus must be applied in a particular manner. If the end of the finger be made to strike quickly, but lightly, the surface of the tongue at its tip, or its edge near the tip, so as to affect not the substance of the organ, but merely the papillæ, a taste sometimes acid, sometimes saline, like the taste produced by electricity, will be distinctly perceived. The sensation of taste thus induced will sometimes continue several seconds after the application of the mechanical stimulus.—*Translator.*

† According to the generally received doctrines of physics, the heating power of light is due to calorific rays distinct from those which produce the sensations of light and colours in the eye.

The effects of the action of electricity on the nerves of common sensation or feeling, are neither the sensation of light, of sound, of smell, nor of taste, but those proper to the nerves of feeling, namely, the sensations of pricking, of a blow, &c.

Chemical influences also probably produce different effects on different nerves of sense. We have, of course, but few facts illustrating their action on these nerves; but we know that in the sensitive nerves of the skin they excite the different kinds of common sensation,—as the sensations of burning, pain, and heat; in the organ of taste, sensations of taste; and, when volatile, in the nerves of smell, the sensations of odours. Without the infliction of great injury on the textures, it is impossible to apply chemical agents to the nerves of the higher senses, sight and hearing, except through the medium of the blood. Chemical substances introduced into the blood act on every nerve of sense, and excite in each a manifestation of its properties. Hence the internal sensations of light and sound, which are well known to result from the action of narcotics.

IV. *The peculiar sensations of each nerve of sense can be excited by several distinct causes internal and external.*

The facts on which this statement is founded, have been already mentioned; for we have seen that the sensation of light in the eye is excited:

1. By the undulations or emanations which from their action on the eye are called light, although they have many other actions than this; for instance, they effect chemical changes, and are the means of maintaining the organic processes in plants.
2. By mechanical influences; as concussion, or a blow.
3. By electricity.
4. By chemical agents, such as narcotics, digitalis, &c. which, being absorbed into the blood, give rise to the appearance of luminous sparks, &c. before the eyes independently of any external cause.
5. By the stimulus of the blood in the state of congestion.

The sensation of sound may be excited in the auditory nerve:

1. By mechanical influences, namely, by the vibrations of sonorous bodies imparted to the organ of hearing through the intervention of media capable of propagating them.
2. By electricity.
3. By chemical influences taken into the circulation; such as the narcotics, or alterantia nervina.
4. By the stimulus of the blood.

The sensation of odours may be excited in the olfactory nerves:

1. By chemical influences of a volatile nature,—odorous substances.
2. By electricity.

The sensation of taste may be produced:

1. By chemical influences acting on the gustatory nerves either from without or through the medium of the blood; for, according to Magendie,

dogs taste milk injected into their blood-vessels, and begin to lap with their tongue.

2. By electricity.

3. By mechanical influences; for we must refer to taste the sensation of nausea produced by mechanically irritating the velum palati, epiglottis, and root of the tongue.

The sensations of the nerves of touch or feeling are excited:

1. By mechanical influences; as sonorous vibrations, and contact of any kind.

2. By chemical influences.

3. By heat.

4. By electricity.

5. By the stimulus of the blood.

V. *Sensation consists in the sensorium receiving through the medium of the nerves, and as the result of the action of an external cause, a knowledge of certain qualities or conditions, not of external bodies, but of the nerves of sense themselves; and these qualities of the nerves of sense are in all different, the nerve of each sense having its own peculiar quality or energy.*

The special susceptibility of the different nerves of sense for certain influences,—as of the optic nerve for light, of the auditory nerve for vibrations, and so on,—was formerly attributed to these nerves having each a specific irritability. But this hypothesis is evidently insufficient to explain all the facts. The nerves of the senses have assuredly a specific irritability for certain influences; for many stimuli, which exert a violent action upon one organ of sense, have little or no effect upon another: for example, light, or vibrations so infinitely rapid as those of light, act only on the nerves of vision and common sensation; slower vibrations, on the nerves of hearing and common sensation, but not upon those of vision; odorous substances only upon the olfactory nerves. The external stimuli must therefore be adapted to the organ of sense—must be "homogeneous:" thus light is the stimulus adapted to the nerve of vision; while vibrations of less rapidity, which act upon the auditory nerve, are not adapted to the optic nerve, or are indifferent to it; for, if the eye be touched with a tuning-fork while vibrating, a sensation of tremors is excited in the conjunctiva, but no sensation of light. We have seen, however, that one and the same stimulus, as electricity, will produce different sensations in the different nerves of the senses; all the nerves are susceptible of its action, but the sensations in all are different. The same is the case with other stimuli, as chemical and mechanical influences. The hypothesis of a specific irritability of the nerves of the senses for certain stimuli, is therefore insufficient; and we are compelled to ascribe, with Aristotle, peculiar energies to each nerve,—energies which are vital qualities of the nerve, just as contractility is the vital property of muscle. The truth of this has been rendered more and more evident in recent times by the investigation of the so-called "subjective" phenomena of the senses by Elliot, Darwin, Ritter, Goethe, Purkinje, and Hjort. Those phenomena of the senses, namely, are now styled "subjective," which are produced, not by the usual stimulus adapted to the particular nerve of sense, but by others which do not usually act upon it. These important phenomena were long spoken of as "illusions of the senses," and have been regarded in an erroneous point of view; while they are really true actions of the senses, and must be studied as fundamental phenomena in investigations into their nature.

The sensation of sound, therefore, is the peculiar "energy" or "quality" of the auditory nerve; the sensation of light and colours that of the optic nerve; and so of the other nerves of sense. An exact analysis of what takes place in the production of a sensation would of itself have led to this conclusion. The sensations of heat and cold, for example, make us acquainted with the existence of the imponderable matter of caloric, or of peculiar vibrations in the vicinity of our nerves of feeling. But the nature of this caloric cannot be elucidated by sensation, which is in reality merely a particular state of our nerves; it must be learnt by the study of the physical properties of this agent, namely, of the laws of its radiation, its development from the latent state, its property of combining with and producing expansion of other bodies, &c.

All this again, however, does not explain the peculiarity of the sensation of warmth as a condition of the nerves. The simple fact devoid of all theory is this, that warmth, as a sensation, is produced whenever the matter of caloric acts upon the nerves of feeling; and that cold, as a sensation, results from this matter of caloric being abstracted from a nerve of feeling.

So, also, the sensation of sound is produced when a certain number of impulses or vibrations are imparted, within a certain time, to the auditory nerve: but sound, as we perceive it, is a very different thing from a succession of vibrations. The vibrations of a tuning-fork, which to the ear give the impression of sound, produce in a nerve of feeling or touch the sensation of tickling; something besides the vibrations must consequently be necessary for the production of the sensation of sound, and that something is possessed by the auditory nerve alone. Vision is to be regarded in the same manner.

The essential nature of these conditions of the nerves, by virtue of which they see light and hear sound,—the essential nature of sound as a property of the auditory nerve, and of light as a property of the optic nerve, of taste, of smell, and of feeling,—remains, like the ultimate causes of natural phenomena generally, a problem incapable of solution.

The accuracy of our discrimination by means of the senses depends on the different manner in which the conditions of our nerves are affected by different bodies; but the preceding considerations show us the impossibility that our senses can ever reveal to us the true nature and essence of the material world. In our intercourse with external nature it is always our own sensations that we become acquainted with, and from them we form conceptions of the properties of external objects, which may be relatively correct; but we can never submit the nature of the objects themselves to that immediate perception to which the states of the different parts of our own body are subjected in the sensorium.

VI. *The nerve of each sense seems to be capable of one determinate kind of sensation only, and not of those proper to the other organs of sense; hence one nerve of sense cannot take the place and perform the function of the nerve of another sense.*

The sensation of each organ of sense may be increased in intensity till it becomes pleasurable, or till it becomes disagreeable, without the specific nature of the sensation being altered, or converted into that of another organ of sense.

With respect to the sense of smell, it is evident that Magendie was deceived in ascribing the power of distinguishing odours to the nasal branches of the fifth nerve, after the destruction of the olfactory nerves; since the stimuli which he applied—for instance, acetic acid, liquor ammoniæ, oil of lavender, and oil of dippel,—are themselves strong excitants of the common sensibility of the mucous membrane. (*Eschricht, Magendie's Journal de Physiol.* t. vi. p. 339.) In all accurately observed cases of absence of the olfactory nerves, the true sense of smell has been wanting. (*Eschricht, loc. cit.*)

No one can deny the possibility of the optic nerves influencing the nerves of the other senses, to the extent in which one nerve can act on another, through the medium of the brain. What an extensive affection of the nerves is seen in neuralgia! what manifold disturbances of the organs of sense result from a nervous condition which has its source in the viscera of the abdomen! How common in such cases are imperfection of vision, noises in the ears, &c.! although it is certain that much which is laid to the score of the abdomen has a much deeper source, namely, irritation of the spinal cord.

It is thus, also, that we must regard the sympathy of the optic nerve with the frontal branch of the fifth, and those cases of amaurosis observed to follow injury of the frontal nerve; though it would perhaps be more correct to explain such affections, which according to my experience are now but rarely seen, as the result of concussion of the eye and optic nerve produced by a blow on the forehead.

Among the well-attested facts of physiology, again, there is not one to support the belief that one nerve of sense can assume the functions of another. The exaggeration of the sense of touch in the blind will not in these days be called seeing with the fingers; the accounts of the power of vision by the fingers and epigastrium, said to be possessed in the so-called magnetic state, appear to be mere fables, and the instances in which it has been pretended to practise it, cases of deception. The nerves of touch are capable of no other sensation than that of touch or feeling. Hence, also, no sounds can be heard except by the auditory nerve; the vibrations of bodies are perceived by the nerves of touch as mere tremours, a sensation wholly different in its nature from sound; though it is indeed even now not rare for the different modes of action of the vibrations of bodies upon the sense of hearing, and upon that of feeling, to be confounded. Without the organ of hearing with its vital endowments, there would be no such a thing as sound in the world, but merely vibrations; without the organ of sight, there would be no light, colour, nor darkness, but merely a corresponding presence or absence of the oscillations of the imponderable matter of light.

VII. *It is not known whether the essential cause of the peculiar "energy" of each nerve of sense is seated in the nerve itself, or in the parts of the brain and spinal cord with which it is connected; but it is certain that the central portions of the nerves included in the encephalon are susceptible of their peculiar sensations, independently of the more peripheral portion of the nervous cords which form the means of communication with the external organs of sense.*

VIII. *The immediate objects of the perception of our senses are merely particular states induced in the nerves, and felt as sensations either by the nerves themselves or by the sensorium; but inasmuch as the nerves of the senses are material bodies, and therefore participate in the properties of matter generally, occupying space, being susceptible of vibratory motion, and capable of being changed chemically as well as by the action of heat and electricity, they make known to the sensorium, by virtue of the changes thus produced in them by external causes, not merely their own condition, but also properties and changes of condition of external bodies. The information thus obtained by the senses concerning external nature, varies in each sense, having a relation to the qualities or energies of the nerve.*

Qualities which are to be regarded rather as sensations or modes of reaction of the nerves of sense, are light, colour, the bitter and sweet tastes, pleasant and unpleasant odours, painful and pleasant impressions on the nerves of touch, cold and warmth: properties which may belong wholly to external nature are "extension," progressive and tremulous motion, and chemical change.

The sense of touch has a much more extended sphere of action for the perception of space than has the sense of vision; but its perception of this quality of external bodies is much less accurate, and considerable portions of the surface of the body or skin are in many instances represented in the sensorium by very few nervous fibres; hence, in many parts of the surface, impressions on two points considerably removed from each other are, as E. H. Weber has shown, felt as one impression. Although the senses of vision, touch, and taste are all capable of perceiving the property of extension in space, yet the quality of the sensations which give the conception of extension is different in each of these senses; the sensation in one is an image of which the essential quality is light; in another, a perception of extension with any of the modifications of the quality of touch, between pain, cold, heat, and pleasure; in the third, a perception of extension with the quality of taste.

The distribution of nerves of common sensation throughout the entire mass of the limbs, indeed throughout most parts of our body, gives to our sense of touch the faculty of distinguishing the extension of our own body in all its dimensions; for each point in which a nervous fibre terminates is represented in the sensorium. Collision with other bodies also, if forcible enough, may excite sensation to a certain depth in the mass of our body, and produce the perception of contusion in all the dimensions of the "cube." Usually, however, the three senses which make us acquainted with the space occupied by bodies, submit to our perception the property of superficial extension only, owing to the exciting causes acting only on the sentient surfaces. The sense of touch has, however, here this advantage over the sense of vision, that the parts endowed with it can be made to embrace a body in several directions; and although the sensation even then affords essentially only a perception of superficial extension, namely of that of the surface of our body corresponding to the surfaces of the object, yet the mind, by taking into account the movements required for the embrace of the object, obtains from a sensation of superficial extent an idea of a body with a certain cubic capacity.

There exists in this respect less real difference between the sense of vision and that of touch than is generally supposed. To place them on an equality, it is only requisite that the eye should be able to change its position so as to look towards the different surfaces of an object; and this defect can be supplied by changing the relative position of our body and the object.

The motion of tremours, or vibrations, is perceived by several senses. This faculty is most evident in the cases of hearing and touch; but even the retina and optic nerve appear to be capable of distinguishing such impressions.

The vibrations which in the organ of hearing give rise to the sensation of sound, are perceived by nerves of touch in the skin as tremours frequently attended with the general impression of tickling; for instance, when a vibrating body, such as a tuning-fork, is approximated to a very sensible part of the surface.

The faculty of discerning the rate of succession of impressions is possessed by all the senses, though in a high degree only by the auditory nerves, in which its delicacy is very remarkable.

The eye can communicate to the sensorium the image of a vibrating body, and can distinguish the vibrations when they are very slow; but here the vibrations are not communicated to the optic nerve in such a manner that the latter repeats them, or that it receives their impulses; while in the ear the vibrations can be imparted directly to the auditory nerve, in consequence of this nerve being spread out on parts which contain the "fluid of the labyrinth."

We are made acquainted with chemical actions by several senses, but principally by taste, smell, and touch, and by each of these senses in the mode proper to it. Volatile bodies disturbing the conditions of the nerves by a chemical action, exert the greatest influence upon the organ of smell; and many matters act on that sense which produce no impression upon the organs of taste and touch,—for example, many odorous substances, as the vapours of metals, of lead for instance, and of many minerals, &c.

It cannot, however, be stated as a general rule that volatile substances are perceived only by the sense of smell; for the same substances are also capable of impressing the senses of touch and taste, provided they are of a nature adapted to disturb chemically the condition of those organs, and in the case of the organ of taste are dissolved by the fluids covering it. Some volatile substances—as, the vapours of horseradish and mustard, and acrid suffocating gases,—act very powerfully upon the common sensitive nerves of certain tracts of mucous membrane, as the conjunctiva and the mucous membrane of the lungs, exciting merely modifications of common feeling; many volatile matters also excite the sensations of burning, pain, &c. in the organ of touch when the skin is denuded of its epidermis.

Fluid bodies, applied to the organs of touch and taste, produce chemical disturbances in their nerves, which excite in each a different sensation; mustard, alkalies, acids, and salts, produce upon the skin, and upon the tongue, totally different effects. Their chemical action must primarily be the same; but the reaction excited differs according to the property of the nerves. On the tongue, however, both results are most probably produced in different nervous fibres at the same time, and by the same substance. Of all the nerves of sense, that of taste is most exposed to chemical influences, and is most affected by very slight modifications of the chemical constitution of bodies. The different conditions as to sensation, into which the nerves of touch can be thrown by chemical agents, are not by any means so numerous; moreover, these nerves are, at least upon the skin, (not on the mucous membranes,) protected from chemical influences by the epidermis.

IX. *That sensations are referred from their proper seat towards the exterior, is owing, not to anything in the nature of the nerves themselves, but to the accompanying idea derived from experience.*

To know the first independent action of our senses distinct from the results of their education, it would be necessary that we had a full recollection of the first impressions made upon them independently of the ideas obtained through their means. This is impossible. Obscure ideas arise even from the first impressions on the senses of the child. It only remains for us then to analyse the act of sensation and the idea with reference to their real import. Doing this, we find in the act of the mind which accompanies sensation, opposed to each other, *the percipient conscious subject*, or self, of the sentient body whose conditions, whether internal or determined from without, are objects for this "conscious self," and the *external world*, with which the sentient body is brought into collision. To the mental consciousness,—to the "self" of the animal being,—every sensation, every motive from without, every "passion" in the logical sense, is something external. The "self" of the individual opposes itself as a free "subject" to the most intense sensations,—to the most tormenting pains. The limb which gives us pain can be removed without the integrity of the individual spirit being diminished; the "self" of the being may be deprived of most of the limbs (parts) of the organic body, and yet be itself as perfect as before; but we have thus far made no distinction between the "exterior" which the organised limbs of our body form in relation to the consciousness of our "self," and the "exterior" which the external world itself forms with regard to our body. The origin of this distinction can be recognised most easily in the sense of touch, which is the first to come into collision with the external world. If we imagine a human being, in which—as in the fœtus in utero; for example,—the sense of vision has never received any impressions, and in which sensations of touch merely have been excited by impressions made upon its body from without, it is evident that the first obscure idea excited could be no other than that of a sentient passive "self" in contradistinction to something acting upon it. The uterus, which compels the child to assume a determined position, and gives rise to sensations in it, is also the means of exciting in the sensorium of the child the consciousness of something thus distinct from itself and external to it. But how is the idea of two "exteriors,"—of that which the limbs of the child's body form in relation to its internal self, and of the true exterior world,—developed? In a twofold manner. In the first place, the child governs the movements of its limbs, and thus perceives that they are instruments subject to the use and government of its internal "self," while the resistance which it meets with around is not subject to its will, and therefore gives it the idea of an absolute exterior. Secondly, the child will perceive a difference in the sensations produced, according as two parts of its own body touch each other, or as one part of its body only meets with resistance from without. In the first instance, where one arm, for example, touches the other, the resistance is afforded by a part of the child's own body, and the limb thus giving the resistance becomes the subject of sensation as well as the other. The two limbs are in this case external objects of perception, and percipient at the same time. In the second instance, the resisting body will be represented to the mind as something external and foreign to the living body, and not subject to the internal "self." Thus will arise in the mind of the child the idea of a resistance which one part of its own body can offer to other parts of its body, and at the same time the idea of a resistance offered to its body by an absolute "exterior." In this way is gained the idea of an external world as the cause of sensations. Though the sensations of the being actually inform him only of the states of himself, of his nerves, and of his skin, acted on by external impressions, yet, henceforth, the idea of the perception of the external cause becomes inseparably associated with the sensation of touch; and such the condition of sensation in the adult. If we lay our hand upon a table, we become conscious, on a little reflection, that we do not feel the table, but merely that part of our skin which the table touches; but, without this reflection, we confound the sensation of the part of the skin which has received the impression with the idea of the resistance, and we maintain boldly that we feel the table itself, which is not the case. If the hand be now moved over a greater extent of the table's surface, the idea of a larger object than the hand can cover is obtained. If, to encompass the resisting object, the hand require to be moved in different directions and planes, the idea of surfaces applied to each other in different directions is conceived, and thus the notion of an external solid body occupying space obtained.

X. *The mind not only perceives the sensations and interprets them according to ideas previously obtained, but it has a direct influence upon them, imparting to them intensity. This influence of the mind, in the case of the senses which have the power of distinguishing the property of extension in objects, may be confined to definite parts of the sentient organ; in the sense gifted with the power of distinguishing with delicacy intervals of time, it may be confined to particular acts of sensation. It also has the power of giving to one sense a predominant activity.*

The attention cannot be directed to many impressions at the same time: in proportion as coetaneous impressions on the senses become numerous, the sensations diminish in intensity, or the mind receives one only with distinctness; while the others are only obscurely, or not at all perceived. If the attention be withdrawn from the nerves of sense, and engaged in intellectual contemplation, deep speculations, or an intense passion, the sensations of the nerves make no impression upon the mind; they are not perceived,—that is to say, they are not communicated to the conscious "self," or with so little intensity, that the mind is at the moment, on account of being quite preoccupied by some other idea, unable to retain the impression, or only recollects it some time after, when the equilibrium of the sensorium is restored, and it is freed from the preponderating influence of the idea which had occupied it. The acuteness which individual senses acquire when others are quite inactive, is therefore readily intelligible; the attention is no longer divided between the several senses, but is wholly engaged in the analysis of the sensations of one.

The blind man acquires such an extraordinary acuteness of touch, as to distinguish with facility the minute elevations on the surface of money, for example; sometimes, indeed, he is able to discriminate between the corpus or grain of one colouring matter and that of another.

Are there new or peculiar senses possessed by some animals in addition to the generally recognised ones?—In concluding this introduction to the physiology of the senses, the question naturally presents itself: Is the number of the senses limited? may not some animals be endowed with other senses besides those which we possess? The error into which Spallanzani fell, in ascribing a peculiar sense to bats on account of their expertness of flight along the surface of walls when they could not see them, is well known. Many persons again have ascribed to animals a peculiar sense by reason of their foreknowledge of the changes of weather. Since the state of the atmospheric pressure, the quantity of watery vapour in the atmosphere, temperature, and electricity, have so marked an influence on the animal œconomy of our own bodies, that we are sensible of changes which they undergo, the possibility of such and even greater influences on animals may very well be conceived; but even great dependence on the state of the atmosphere with reference to sensation does not require a new sense. On the contrary, the state of the atmosphere may be perceived by its influence on the whole nervous system, and particularly through the sensations of the nerves which are most numerous, and most exposed to the atmosphere, namely, the nerves of touch or common sensation. The supposed existence of a special sense for the perception of electricity in some animals is, *à priori*, not admissible; for electricity acts, as we have already shown, upon all the senses, exciting in each the sensation peculiar to it.

The essential attribute of a new sense is, not the perception of external objects or influences which ordinarily do not act upon the senses, but that external causes should excite in it a new and peculiar kind of sensation different from all the sensations of our five senses. Such peculiar kind of sensation will depend on the powers of the nervous system; and the possibility of the possession of such a faculty by some animals cannot, *à priori*, be denied: no facts, however, are known which establish the existence of such a new mode of sensation, and it is, in fact, quite impossible to have any experience of the nature of a sensation in any other beings than ourselves.

Some physiologists have regarded the internal sensations of the sense of touch by which we are made acquainted with the different states of our body, as something different from that sense, and have ranked the conscious perception of the different parts of our frame (*Gemeingefühl*, *cœnæsthesis*, or common feeling,) almost on a level with the other senses. This is an error; for the sensations here alluded to are of the same nature as those of the skin which are excited from without, only that in many organs they are more undefined and obscure. Moreover, it is indifferent whether a sense be excited to action from within, or from without; in no sense do we perceive any essential difference between the sensations thus produced. The designation, "sense of touch," expresses certainly a special relation of that sense to the external world; but the act of "touch" merely renders manifest the energies of this sense, which everywhere resides in the same nerves—the mixed cerebral and spinal nerves with double roots. Something analogous to the act of touch is observed in the other senses; it is an action of the sense voluntarily directed; and in the same way there is a voluntary hearing (listening), seeing (looking), tasting, and smelling.[*]

SECTION I.

OF VISION.

CHAPTER I.

I. OF THE POSSIBLE FORMS OF ORGANS OF VISION.

From the facts stated in the introduction to the physiology of the senses we have learnt that light and colour are sensations of the optic nerve and retina, and that the appearance of darkness before the eyes is the sensation proper to the state of repose, or unexcited condition of the retina. The sensations of light and colour are produced, in the midst of this darkness, wherever aliquot parts of the retina are excited by any internal stimulus, such as the blood, or by an external stimulus, such as mechanical pressure, electricity, &c. The seat of the sensation varies with the part of the retina acted on by the stimulus. The luminous spectrum produced by pressing upon one side of the closed eye is always seen upon the opposite side; and those produced by exerting pressure upon the upper or lower part of the retina are also seen at the opposite points of the field of vision. If the pressure is made by means of a small body, such as, for example, the blunt point of any instrument, and the parts of the retina affected by it consequently of limited extent, the luminous image is also small. If, on the contrary, the pressure be made over a greater extent at the angle of the eye with the edge of some body, the image produced has a corresponding extent. These images are not defined, on account of the pressure upon the eyeball through the eyelids and coats of the eye being necessarily diffused to a certain distance around the space which the pressing body itself would act upon. If, however, it were possible to confine the pressure accurately to determine portions of the retina, we should doubtless be able to produce perfectly defined images by mechanical means. The physical imponderable principle which has received the name of light, because the luminous affections of the retina are usually caused by it, produces, when the whole of that nervous expansion is uniformly affected by it, the sensation of a diffused light occupying the whole field of vision, in place of the darkness seen before the eyes when the retina is not excited. But if this well-adapted and salutary stimulus of the retina acts only on definite parts of the retina, luminous images are formed at those parts, and the shadows of these images are the intervening parts of the retina which are not stimulated to the sensation of light, and consequently retain the sensation of darkness, as when the eyes are closed. It is thus that we are enabled to see bodies, which either themselves radiate the principle called light,—luminous bodies, or, being impermeable by that principle, reflect it when they receive it from other bodies, and so direct it into the sentient eye. The sensation of light is then produced at a determinate part of the eye, and we think to see the body, which, however, merely reflects into the eye the principle capable of exciting the sensation of light, which it has itself received from elsewhere.

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[*] The general treatises on the physiology of the senses are: Le Cat, Traité des Sens. Amst. 1744.—Elliot, Observations on Vision and Hearing. London. 1780. (Uber die Sinne. Leipz. 1785.—Steinbuch, Beiträge zur Physiologie der Sinne. Nürnberg, 1811.—Tourtual, Die Sinne des Menschen. Münster, 1827.)

II. THE EYE OF MAN AND VERTEBRATE ANIMALS.

This is not the place to treat of the structure of the different parts of the eye, and to describe its general anatomy. It is our object here to refer merely to the principal structural relations important for the function of vision.

Appendages of the eyes.—The eye-lids—The eye-lids may be entirely wanting, the skin passing in that case simply over the surface of the eye, as in many fishes and several Amphibia,—for example, in the Proteida and Pipa; or the skin forms eye-lids (palpebræ), which may be either single or double, or be united into a circular zone with a central opening, as in the chameleon. In addition to the ordinary eye-lids, there is seen in some animals the membrana nictitans, or third eye-lid, which exists in a rudimentary state even in Mammalia, is most fully developed in birds and reptiles, and exists again in a less perfect form in fishes, namely, in several genera of the shark family.

Of similar nature to the membrana nictitans is a spectacle-like transparent space in the inferior eye-lid of some lizards, as several of the Scincoid family, which can be drawn over the eye; and, while it corresponds to the cornea, does not prevent vision. The immovable capsule in front of the eye in serpents is, on the contrary, quite a peculiar structure.

The *lachrymal apparatus* is absent in cetaceous Mammalia, in Amphibia, and in fishes.

The tunics of the eye.—The *sclerotica* in many animals exhibits a tendency to be cartilaginous or bony. In birds, Chelonia, and lizards, the anterior part of the sclerotica immediately around the cornea contains a ring of osseous plates, of which the edges either lie one over the other in an imbricated manner, or are merely in apposition; and the sclerotic coat in fishes generally contains two large plates of cartilage.

The *choroid* is in animals divisible into two laminæ,—the external proper choroid, and the internal membrana Ruyschiana; in fishes the external lamina has generally a silvery lustre, while the internal is covered with pigment. Between the two at the point of entrance of the optic nerve is situated the glandula choroidalis, a body of a horse-shoe shape, which receives a large quantity of blood.* The *ciliary ligament* is in man and in Mammalia of fibrous structure, but in birds appears to be muscular. The inner surface of the choroid is in all animals covered by the *membrana pigmenti*, which is composed of flattened cells, often of hexagonal form, containing the granules of pigment. In albinoes these cells contain no pigment. In several animals it is normally deficient at certain parts of the eye, which then either are white, or have a metallic lustre, and are called the *Tapetum*. The tapetum at the posterior and external part of the eye in ruminant animals is covered with the cells of the pigment membrane, but the pigment itself is wanting. The metallic lustre and iridescent colour of the tapetum in these animals appears to be owing to the structure of the choroid producing "interference" of light, and not to the presence of any material colouring matter; they are therefore lost when the choroid is dried.† The perfectly white colour of the tapetum, which occupies an accurately defined triangular space at the bottom of the eye of carnivorous animals, is not destroyed by drying, and is due to a peculiar pigment. The smallest quantity of light entering the eye is reflected by the tapetum; and hence it is that the eyes of animals provided with this structure are luminous in a very faint light, though not in perfect darkness (see page 95).

The *corpus ciliare*, or *ciliary processes*, do not exist in fishes, with few exceptions; but a *falciform process* passes through a cleft in the retina, and attaches itself firmly to the margin of the lens, which is also held in its position by a small pear-shaped body (the campanula Halleri).

The *iris* is mobile in most animals, but in the osseous fishes is scarcely, if at all, so. In the horse, narwhale, lama, and rays, it presents at the upper border of the pupil a veil-like appendage. The *pupil* is sometimes round; sometimes elongated transversely, as in the Ruminantia; sometimes in the perpendicular direction, as in the cat family and the crocodile; sometimes triangular, as in the brown or fire toad, Rana bombina, &c.

The *pecten* or *marsupium* is characteristic of birds; it is a pyramidal plicated process provided with pigment, which has its origin in the choroid coat, passes through an opening in the retina, at the bottom of the eye, into the middle of the vitreous humour in the direction of the margin of the lens; its situation is the posterior and external part of the cavity of the eye. Lizards have a trace of the pecten, and the processus falciformis of fishes is perhaps an analogous structure.

Transparent media of the eye.—The inimate structure of the lens has been already described at page 109. It consists of concentric lamellæ enclosed one within the other. It has been observed that these lamellæ, or capsules, are again formed of fibres by which the thickness of each is determined. Dr. Brewster has shown that the fibres are united to each other by toothed margins, which are most distinct in fishes.

Optic nerve and Retina.—The most remarkable peculiarities of structure are presented by these parts. The optic nerve is always constituted of primitive nervous fibres, which are similar to those of the brain, being very minute, much more so than those of other nerves. The nerve thus composed either presents a merely fibrous structure, as in man: or these fibres are arranged in particular situations, as at the chiasma, into laminæ; the laminæ of one nerve passing at this part between those of the other, as in birds, reptiles, and Amphibia: or, lastly, the whole optic nerve, in its course from the brain to the eye, is membranous; this structure, which Malpighi discovered in the sword fish, appears to be characteristic of all fishes. When the sheath of the optic nerve in these animals is laid open, the optic nerve is seen, having the form of a membrane with free borders folded together like a curtain; and it would seem that the retina is formed simply by the unfolding of this membrane. (*J. Müller, Physiol. des Gesichts-sinnes*, tab. 3, fig. 19.) The retina in the eye of fishes has at least two corresponding free borders, being cleft and gaping from its anterior margin to the fundus of the eye.

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* On the structure of this body, see Mr. Owen's remarks in the third volume of the Physiol. Series of the Catalogue of the Hunterian Museum; and Mr. Wharton Jones's paper in the twenty-first volume of the Med. Gazette, p. 650.

† It has been shown by Hessentein, Valentin (Repertor. 1837, p. 246), and Mr. H. J. Carter, (Medical Gazette, Jan. 5, 1839,) that the action of the tapetum of ruminant animals in decomposing light depends on its being formed of parallel waving fibres like those of tendon. The influence of these fibres in producing the iridescent colours is explicable on the principle of "interference."

The union of the two optic nerves soon after their origin, or the optic commissure or chiasma, next requires our attention. The varieties in structure with relation to this part may be stated as follows:—1. The structure which exists in osseous fishes. Here the two nerves are connected after their origin by a slender transverse commissure; and then form no chiasma, but simply decussate without their fibres mingling, the right nerve going to the left eye, and the left nerve to the right eye. 2. The structure proper to cartilaginous fishes. Here the nerves do not decussate as in osseous fishes, but are closely connected by a commissure, the internal structure of which is not known; this form approaches very nearly to the chiasma of the higher animals. 3. The chiasma of Amphibia, reptiles, and birds, which in external appearance is similar to that of Mammalia, but has an internal laminated structure; the laminæ of one optic nerve passing between those of the other nerve, like the crossed fingers of opposite hands. It is not yet known whether all the fibres of the two optic nerves decussate here, or whether a portion is continued to the eye of the same side as that of their root. 4. The chiasma of Mammalia and man. The laminated structure is here absent. There is a partial decussation of the fibres of the two nerves, while another portion is continued to the retina of the same side. This structure is more evident in mammiferous animals than in man. The superior and external portion of each root of the optic nerve is, in the horse, continued to the eye of the same side; the rest of the fibres decussate, and form part of the nerve of the opposite side.*

The microscopic structure of the *retina* has been recently elucidated by the discoveries of Treviranus,† with which the observations of Gottsche‡ also are in accordance. The following description takes account of all the most important points in the structure of this part:—The retina consists of three principal layers; an external pulpy or pavement-like layer of granules, a middle fibrous layer, and an internal layer composed of erect cylinders, which is the continuation of the fibrous layer. The optic nerve, at its entrance into the eye, divides into the cylindrical nervous fibres which radiate out in the middle fibrous lamina of the retina. Each nervous fibre, or each fasciculus of several fibres, bends, as Treviranus discovered, at a certain point of its course, from the horizontal direction towards the opposite internal surface of the membrane, where it ends as a papilla. Although the three layers of the retina certainly exist, and although the rod-shaped bodies composing its internal lamina are very distinct, having been seen by Volkmann, E. H. Weber, Gottsche, Ehrenberg, and myself, yet the essential nature and mode of connection of these bodies with the fibres of the fibrous layer are still involved in obscurity. It is a question, namely, whether the rod-shaped bodies correspond exactly in number to the nervous fibres, and whether each fibre actually corresponds to one of those bodies, or whether the latter are superposed in series upon the fibres of the fibrous layer.

Conditions necessary for vision.—Owing to ignorance of the physical conditions necessary for vision, it has become a current opinion that there are animals endowed with the perception of light by their skin. It cannot be doubted that many animals which have no eyes are sensible of the influence of the principle of light; thus, Rapp (*Nova Acta Acad. Nat. Cur.* xiv. p. 2,) observed that the Veretillum cynomorium, one of the Polypifera, avoids the light, and prefers shaded situations.§ But, with respect to the mode of action of light on such animals, we have no facts to prove that it produces in their skin, or the entire surface of their body, really the sensation of light, and not another kind of sensation. We ourselves are sensible of the action of light on our skin by the sensation of warmth which it produces, but do not thence derive any sensation of light; for, as far as we can judge from facts, the optic nerve alone is susceptible of that sensation. The action of light on the lower animals destitute of eyes may be similar to its action on the surface of our body. Even plants are strongly affected by its influence: the direction in which they grow and spread their branches is regulated by their tendency to bend towards the light.

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* J. Müller, Physiol. des Gesichts-sinnes, tab. 2 figs. 4, 5.

† Beiträge zur Aufklärung des Organischen Lebens. Bremen.

‡ Pfaff's Mittheilungen aus dem Gebiete der Medicin, 1836. Heft 3, 4. The most internal fibres of the cerebral portion of each optic nerve are, according to Mr. Mayo, continuous in the commissure with corresponding fibres of the opposite nerve: these would be, as Mr. Solly remarks, strictly commissural fibres. The innermost fibres of the nerves beyond the commissure are also described by Mr. Mayo to be united in a similar manner by a sort of loop, and not to be continued backwards through the chiasma.

§ With respect to the Hydræ no decided result has been obtained, notwithstanding the experiments of Trembley, Baker, Hanow, Roesel, Schaeffer, Bonnet, and Goeze.

The connection of the sensation of light solely with special nerves endowed with a specific sensibility is proved by the actual existence of eyes in many of the animals lowest in the scale of organisation. Many of the Annelida, as several of the Nereida, several species of Eunice, Phyllodoce, Spio, and Nais, almost all the Hirudo family, and the Aphrodrite heptacera, have dark eye-dots on their head. An annelide nearly allied to Sabella, and observed by Ehrenberg, Henle, and myself, has two such dark points at each extremity of its body; and it creeps both forwards and backwards. The Hirudo medicinalis has, as E. H. Weber pointed out, ten dark eye-dots on its head, which in the embryo are distinctly visible, the body being yet transparent.

A second critical remark, which suggests itself in connection with this subject, relates to the opinion that, by virtue of the exaltation or transposition of sensibility, it is possible for persons to see with the skin.

It is a known fact that we cannot, by means of the fingers, recognise colours as such; although it may be possible to distinguish the corpus or grain of some colouring matters when laid thickly upon a surface, since they are uneven, and adhere to the skin which touches them. The necessity for an optical apparatus for the production of an image upon a percipient membrane sufficiently refutes the notion of persons being able to see with their epigastrium, or with the fingers, when in the so-named magnetic or mesmeric states. Even though the skin of the epigastrium or fingers were susceptible of the sensation of light, which they are not, the perception of objects would yet be impossible, unless there were optical apparatus for collecting the light radiated from certain points of the object upon certain corresponding points of the sensitive surface; and, without such apparatus, the epigastrium and fingers, though they possessed the sensibility for light, would merely be able to distinguish light from darkness. Since, however, these parts are not susceptible of the sensation of light, and since no sense can be transferred from one part to another, it is quite impossible for a person in the magnetic state to have even an obscure perception of light and

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Ingenhouss and Goldfuss relate that the green matter of Priestley collects especially in places exposed to a bright light. This green matter which collects in such situations, may certainly consist of living infusory animalcules, since many of these creatures have a green colour, and many indeed have, according to Ehrenberg's observation, eye-dots. What is usually called the green matter of Priestley, however, often consists merely of the dead remains of green Infusoria, as the Euglena viridis and others.

darkness by means of any other parts than the eyes. Moreover, when the eyes are bound, it is still possible to distinguish the light, and even objects, by slightly raising the eye-lids, as every one well knows who has played at the game of "blind-man's buff;" and persons lying, like the subjects of the pretended magnetic sleep, in the horizontal posture with their eyes bound, can see every part of the room by looking under their bandage. But what well-informed physician can put faith in the fables told by the upholders of animal magnetism? It is quite in accordance with the laws of science that a person sleeping shall have ocular spectra,—we experience them sometimes when the eyes are closed, even before falling asleep,—for the nerves of vision may be excited to sensation by internal as well as by external causes; and so long as a "magnetic" patient manifests merely the ordinary phenomena of nervous action that are seen in other disorders of the nervous system, it is all creditable enough. But when such a person pretends to see through a bandage placed before the eyes, or by means of the fingers or the epigastrium, or to see round a corner and into a neighbouring house, or to become prophetic, such arrant imposture no longer deserves forbearance, and an open and sound exposure of the deception is called for.

III. OF THE PROCESS OF VISION IN EYES WITH CONCENTRATING DIOPTRIC MEDIA.*

In the compound eye of insects and Crustacea vision is effected by the radiating cones transmitting to the optic nerve those rays only of the cone of light emitted by each point of the object, which have the direction of the axis of the cones, or of the radii of the eye, while the rest of the rays are absorbed. In eyes furnished with collective or concentrative refracting media, the cone of light emitted by each point of the object is collected again to a point upon the sentient retina.

The refraction of the rays of light in the eyes of man and the higher Mammalia is, however, threefold. The rays of the cones of light emitted by different points of an object, are first refracted by the cornea and the aqueous humour contained between it and the lens,—that is to say, the rays are bent towards the axis of the cone of light; the media just mentioned having the power of refracting light by virtue of their density being greater than that of the air, and by reason also of their convexity. The rays of each cone of light are again refracted and bent still more towards its central ray or axis by the anterior surface of the lens; this body having a greater density than the aqueous humour, and its anterior surface being convex. The rays are again refracted in passing out of the lens into the less dense medium of the vitreous humour. It can be shown, that a lens has the power of refracting the rays of a cone of light so as to bend them towards the axis of the cone, not only on their entrance from a rarer medium into the anterior convex surface of the lens, but also at their exit from its posterior convex surface, when they pass again into the rarer medium. In this manner the rays of the cones of light issuing from the points of the object are again collected to points; and, if the retina be situated at the proper or focal distance, perfect images of the points will be perceived: but if the retina be not thus situated, but either before or behind that situation,—circular luminous spots, instead of points, will be seen; for the rays have not yet met, or they have already intersected each other, and are again diverging. The retina must therefore be situated at the proper focal distance from the lens, otherwise a defined image will not be formed, or, in other words, the rays emitted by a given point of the object will not be collected into a point upon it. The focal distance of the image is greater, the nearer the object to the lens, and *vice versâ*. The direction given to the rays by their refraction is regulated by that of the central ray, or axis of the cone, towards which the other rays are bent.

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* After the treatises of Treviranus, Tourtual, Hueck, and Volkmann.

We have hitherto regarded those rays of the cones of light which traverse the middle of the pupil, and therefore pass through the crystalline lens near its centre, as determining the situation of the image on the retina. In this supposition, however, there is a slight inaccuracy,—that is to say, a line drawn from a given point of the object through the middle of the pupil would not fall exactly upon the corresponding point of the image on the retina; for even the central rays of a cone of light, when they fall obliquely upon the cornea and lens, suffer refraction from their original direction. Hence it follows that the actual direction of the central ray of a cone of light can be found only by experiment and calculation, and that the law laid down with regard to the optical angle requires some modification.

Since the surface upon which the images are formed in the eye is concave, and from its centre towards its margins gradually approaches the lens, it necessarily follows that the images of objects situated at the sides cannot be so distinct as those of objects nearer to the middle of the field of vision, of which the images are formed at a distance behind the lens exactly corresponding to the situation of the retina. The indistinctness of the side images has, however, other causes besides this. The rays of a cone of light from an object situated at the side of the field of vision do not meet all in the same point, owing to their unequal refraction; but the main cause of the images of objects depicted on the retina becoming less distinct as they are more distant from its centre, seems to lie in a peculiarity of that membrane itself.

The refraction of the rays which pass through the circumference of the lens, and of those traversing its central portion, being unequal in consequence of "spherical aberration," a contrivance for the prevention of indistinctness of vision from this cause was required in the eye, like that employed in optical instruments,—namely, a diaphragm, to cover the circumference of the lens, and to prevent the rays from passing through any part of the lens but its centre; this diaphragm is the iris, and the central opening for the transmission of the rays, the pupil. The iris has, however, this advantage over the diaphragms of optical instruments, that it is mobile,—has the power of dilating and contracting. The dilatation of the pupil in the dark, or in a feeble light, has the good effect of admitting more luminous rays, even though the image is rendered less distinct. But even the image formed by the rays passing through the circumference of the lens when the pupil is much dilated may, under certain circumstances, be well defined; the image formed by the central rays being then indistinct or invisible, in consequence of the retina not receiving these rays where they are concentrated to a focus. The image must be most defined and distinct when the pupil is narrow, the object at the proper distance for vision, and the light abundant; so that, while a sufficient number of rays are admitted, the narrowness of the pupil prevents the production of indistinctness of the image by spherical aberration or unequal refraction.

With respect to the lens, we may remark that it must be more dense and more convex in proportion, as the difference between the density of the medium in which the animal lives, and that of the aqueous humour, is less. In fishes the lens is spherical, and the cornea generally flattened. In animals which live in the air, the cornea is more convex, and the lens much less so.

The interior of the eye, namely, the posterior surface of the iris and ciliary processes, and the inner surface of the choroid, immediately external to the retina itself, is coated with black pigment, which has the same effect as the black colour given to the inner surface of the walls of optical instruments. It absorbs any rays of light which may be reflected within the eye, and prevents their being thrown again upon the retina so as to interfere with the distinctness of the images there formed. This is the use of the pigment on the posterior surface of the iris and ciliary processes. But the coating of the outer surface of the retina by the pigment of the choroid is also important in the same respect; for the retina is very transparent, and if the surface behind it were not of a dark colour, but capable of reflecting the light, the luminous rays which had already acted on the retina would be reflected back again through it, and would fall upon other parts of the same membrane, the consequence of which would be not merely dazzling from the excessive action of light, but also indistinctness of the images. Animals in which the choroid is destitute of pigment, and human albinoes suffer in this way; they are dazzled by daylight, and see best in the twilight.

In many animals, which are most active, and hunt their prey when it is becoming dark, but are sluggish during the day, as in the cat family and other nocturnal animals, the portions of their choroid destitute of pigment, or rather covered with white pigment in place of black, are of service by increasing the action of the luminous rays upon the retina.

The distinctness of the image formed upon the middle portion of the retina is dependent on several very different conditions: namely, 1, on the rays emitted by each luminous point of the object being brought to a perfect focus upon the retina without any halo being produced; 2, on the sufficiency of the illumination; 3, on the small size of the elementary parts of the retina which are susceptible of distinct sensation.

Different Distances of Vision.—The *first* condition, namely, the necessity of the focus of the cones of light falling exactly upon the retina, is the cause of the different distances at which different persons see distinctly; some persons being short-sighted, others long-sighted; while in others, again, there are no such narrow limits to the sphere of distinct vision, their eye being able to adapt itself for the formation of the image upon the retina according to the distance of the object. Since, however, this power of adaptation of the eye for vision at different distances has its limits, there is in every individual a distance at which he sees most distinctly, and at which the focus of the image formed by the refracting media of his eye corresponds most accurately with the situation of his retina. This "distantia visionis distinctæ" may be stated at from five to ten feet [query, inches] in the majority of individuals. Objects which are too near the eye throw very indistinct images upon the retina; a slender body, such as a pin, held close to the eye, cannot be seen at all, or produces only an undefined impression on the retina. Few persons, on the other hand, are able to read print at a much greater distance than twenty inches. The refractive power of the transparent media of the eye is the source of great difference in this respect. Short-sighted or myopic persons see the nearest object distinctly, while they cannot discern distant

:ts; long-sighted persons can see a small body which is not very visible, only ı it is held at a considerable distance from their eyes.

ıe *second* condition for distinctness of vision is an adequate quantity of light; ex- as well as deficiency of light causes the images of objects to be indistinct.

ıe *third* condition is the minute size of the ultimate divisions of the retina capable dependent sensation. An illustration of this is afforded by bodies of which the ıces are marked with very fine alternate black and white lines. Engravings 'ed at such a distance that the images of the black and white lines fall together . portions of the retina of a certain degree of minuteness, cannot be distinguished parate lines, and produce merely the mixed impression of grey; the same remark es to very fine lines of different colours regularly alternating with each other,— ıstance, blue and yellow lines: in this case the impression of green will be pro- d. Hence it is that all mixtures of two different colouring matters are seen, not ro colours mixed, but as a single intermediate colour. There must therefore be ıate portions of the retina in which all simultaneous impressions are perceived as ınly, and are not distinguished as occupying distinct places in the field of vision, when they really are distinct in the image formed by the refracting media. The immediately suggests itself, that these ultimate sentient portions of the retina be the papillæ or rod-shaped bodies of its internal lamina; and it would appear ıble that different luminous rays impinging simultaneously on the different points e surface of such minute portion or papilla of the retina will not be perceived as ıct rays, but that each papilla will receive from all one mixed impression only, will propagate such an impression to the optic nerve. On this supposition the e perceived in these eyes must be composite, like a piece of mosaic-work, in h each elementary portion is in itself homogeneous. In accordance with this , it is found that the ultimate anatomical elements of the retina agree pretty y in size with the smallest portions of the retina ascertained by experiment to ıpable of separate sensation. The smallest angle under which two points can be nguished by many persons is 40″. From this, Smith calculated that the size of mallest portion of the retina endowed with distinct sensation is $\frac{1}{8000}$ of an inch; according to the measurements of Treviranus, the diameter of the papillæ of the a in the rabbit is 0·0033 millim.; in birds from 0·002 to 0·004 millim. Now, 3 millim. equals 0·00011 of an English inch, and 0·004 millim. = 0·00015 of an ish inch. The mean between 0·003, and 0·004 millim., or, as an approximation, een $\frac{1}{6000}$ and $\frac{1}{10000}$ of an inch, being therefore assumed as the diameter of the læ of the retina, the size of these parts would agree very exactly with that of the lest portions of the surface of that membrane capable of distinct sensation. The ırements of the globules of the human retina, taken by E. H. Weber some years ı, also accord with this view: he found their diameter to be between $\frac{1}{8000}$ and of a French inch.

:cording to other data, however, no such agreement is found to prevail; and :mann's observations render it probable that the discriminating power of the retina uch greater than it could be, were the nervous fibres its ultimate elements. eke assumes 30″ as the smallest angle at which an object can be distinguished; iranus could discern a black point 0.00833 of an inch in diameter, upon a white nd, at a distance of 48 inches; and Volkmann calculates that the diameter of the lest image perceived by the retina is 0.000060″. Even this estimate of the dis- ng power of the retina he regards as too low: any eye of moderate power can, he , see a hair 0.002 of an inch in diameter at the distance of 30 inches, when an ·e on the retina of 0·000023 of an inch only would result. A pupil of Von Baer l see a hair $\frac{1}{60}$th of a line in diameter at the distance of 28 inches, in which case :mann calculates that an image $\frac{1}{6,0000014}$ of an inch was perceived in the retina. :mann concludes, therefore, that, even disregarding the last extraordinary instance, ;mallest images perceived in the retina are smaller than the most minute known ɔmical elements of that structure.

/. ADAPTATION OF THE EYE TO VISION AT DIFFERENT DISTANCES.

: will have been perceived, from the facts already stated, that some nges in the internal condition of the eye are necessary for the pur- ɜ of distinct vision at different distances. The focus of the image of distant objects is somewhat nearer to the lens than that of the image of near objects. The amount of the difference in the focal distances for near and distinct objects, as deduced from the refractive powers of the media of the eye, has been calculated by Olbers.* We shall extract some of the results of his calculations, in order to give an accurate idea of the degree of modification required in the eye. The distance of the image from the cornea when the objects were at the distances of 4, 8, and 27 inches, and at infinite distance, so that the rays were essentially parallel, was found to be respectively as follows:

Distance of the object.	*Distance of the image from the cornea.*
Infinite	0·8997 of an inch.
27 inches	0·9189 „
8 „	0·9671 „
4 „	1·0426 „

So that the difference between the focal distances of the images of an object at such distance that the rays are parallel, and of one at the distance of 4 inches, was only 0·143 of an inch. On this calculation the change in the distance of the retina from the lens required for vision at all distances, supposing the cornea and lens to maintain the same form, would not be more than about one line, which might be effected either by elongation of the eye, or by a change in the position of the lens. Dr. Young estimated the necessary change at ⅛th of the length of the axis of the eye.

It will be conceived that the same object might be attained, without any alteration in the distance of the lens from the retina, by a change in the convexity either of the cornea or lens.

Olbers has also calculated the amount of change in the convexity of the cornea which would be required for distinct vision at different distances. The radius of the convexity of the cornea for vision at certain distances, taken for the sake of examples, would be as follows:

Distance of the object.	*Radius of the cornea.*
Infinite	0.333 of an inch
27 inches	0.321 "
20 "	0.303 "
5 "	0.273 "

If the radius of the cornea were capable of modification between 0.333 and 0.300 of an inch, and the long axis of the eye capable of being lengthened the extent of half a line, distinct vision at all distances beyond four lines would be provided for. These results may serve as the basis of the following inquiry.

The absolute necessity of such internal changes in the eye to adapt it for distinct vision at different distances appears a matter of certainty. Nevertheless, some physiologists—as, De La Hire, and Haller, and more recently Magendie, Simonoff, (*Journ. de Physiol.* iv. p. 260,) and Treviranus,†—have called in question the capability of the eye to undergo such internal changes: most cultivators of physics and physiology, however, regard the reality of these changes of adaptation as proved by certain facts. Magendie founds his skepticism on the observation that image in the eye of a white rabbit does not diminish in distinctness n the distance of the object is altered; which is not, however, a stant fact. G. R. Treviranus, from a calculation of the action of es which increase in density towards their interior, arrived at the lusion that with lenses of this structure the focal distance would ain the same whatever the distance of the object, and consequently no adaptation of the eye for different distances is required.

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* See his excellent treatise, De Internis Oculi Mutationibus. Gött. 1780.

† Beiträge zur Anat. u. Physiol. der Sinneswerkzeuge, 1828; and his Beiträge zur Aufklärung der Erschein. u. Gesetze des Organisch. Lebens. 1—3 Heft.

Iuch as we may admire the elegant manner in which Treviranus treated this subject with the aid of mathematics and the laws of cs, yet we must confess that the results of his calculation do not rd with the facts observed in the eye itself. Moreover, Kohlrausch *er Treviranus' Hypothese.* 1837,) controverts the accuracy of viranus's deductions. That the eye does undergo changes to adapt r distinct vision at different distances is indeed proved incontestably imple and accurate experiments. They are as follows:

The power which the eye possesses of accommodating itself to different dis- s is frequently much modified in a short space of time. Not only does the con- use of the eye in regarding near objects induce short-sightedness in children, but ently the same condition is produced as a transient state of a few hours' duration ng-continued use of the microscope. Under such circumstances, the perception jects at 20 feet distance in the street sometimes becomes indistinct, though, be- the eyes could accommodate themselves well both to near and distant objects. has frequently happened to me. The state of myopia thus induced lasts some- s several hours.

If we regard with one eye only (the other being closed) the ends of two needles d one before the other at different distances in the line of the axis of the eye, one be seen distinctly when the other appears indistinct, and *vice versâ.* Both the es lie in the axis of the eye, one over the other; and yet it depends on a voluntary t, the exertion of which can be felt in the eye, whether the first or the second le shall be seen distinctly. So that when with the pupil contracted, as it is for the n of near objects, I fix my eye upon the nearest needle, the focal point of its dis- image being at the central point of the retina, the more distant one, though the al rays only of its cone of light can enter the eye, forms, nevertheless, an indis- circle of light around the same central point of the retina; that is to say, the al rays of the more distant object do not meet in a focus at the central point of the a, but anterior to it. (*Jahrb. f. Wissenschaft. Kritik.* 1829. Oct. 623.) A variation is experiment consists in looking at the head of a pin through a very small open- n a card. Here it is wholly dependent on the will whether the borders of the ing shall be seen distinctly, in which case the head of the pin becomes indistinct; hether this should be seen distinctly, when the borders of the opening in the card to appear defined. Treviranus has not paid sufficient attention to these pheno- ; and his explanation of them, by supposing the attention or nervous action being ferred from one part to another, is very unsatisfactory. The two images of the les fall upon the same point of the retina, one lies over the other, and yet I see the r through the cloud-like image formed by the rays from the other more distinct le, and *vice versâ.* There is here no transferring of the attention from one point e retina to another. An entire leaf covered with letters appears indistinct to me, on as I produce the internal change in my eye necessary for distinct vision at a rent distance, though no object be there.

Scheiner's experiment. (*Scheiner, Oculus, sive Fundamentum Opticum.*)—If two oles be made in a card, at a less distance from each other than the diameter of the l, and if these openings be held before one eye, so that a small object can be seen gh them, this object will appear single at one particular distance from the eye, vhen it is at any other distance it will appear double.

e conclusions to be deduced from this experiment have been pointed out by Por- ld, Young, (*Philos. Transact.* 1801,) Purkinje, Plateau, and Volkmann, and the nentioned physiologist has varied the mode of performing it in several ways.

The experiment of Scheiner proves clearly the necessity of adaptation of the eye for distinct vision at different distances, and at the same time the incorrectness of the hypothesis of Treviranus, since it shows that the image of an object under certain circumstances falls in front of the retina, and under others behind it. An experiment of Beudant and Crahay has the same import. If a pin at the distance of five or six centimeters [2 or 2¼ inches] from the eye be viewed through a pin-hole in a card, and the card be moved from side to side, the needle will appear to move also, but in the opposite direction to the card. This is explicable in accordance with the phenomena of indistinct vision, resulting from the image of the object falling either in front of or behind the retina. Thus, if the rays meet at a focus in front of the retina, they will diverge again after having crossed at the focal point, and will form an indistinct spectrum upon the retina, not a definite image; and if in this case the card in its motion intercept a part of the decussating rays, those from one side only will reach the retina. Hence the apparent shifting of the image. The diffraction of the rays at the margin of the opening in the card, however, has also a share in the production of this phenomenon.

The adaptation of the eye to distinct vision at different distances may be attributed to changes in several different parts, namely, to movements of the iris, to change of place of the lens, to elongation of the axis of the eye, or to alteration in the convexity of the lens or cornea.*

1. The movements of the iris have been considered the means of adaptation by some physiologists, amongst whom are Mile and Pouillet; Professor Mile supposed it to be effected by the inflexion or diffraction of the light at the margin of the pupil, by which the focal distance for the respective rays would be rendered very different. M. Pouillet thought the image would be formed by the central or by the peripheral rays, according as the pupil was contracted or dilated.

2. Elongation and shortening of the axis of the lens were regarded by Dr. Young as the means of accommodation. J. Hunter and Dr. Young ascribed to the lens a contractile power inherent in itself. (*Philos. Transact.* 1794.)

3. Change in the convexity of the cornea was the explanation adopted by Sir E. Home, Englefield, and Ramsden: this change was supposed by Sir E. Home to be effected by the action of the proper muscles of the eye; or, in birds, by the peculiar muscle, discovered by Sir P. Crampton, (*Thomson's Annals of Philosophy*, vol. i. 1813, p. 170,) at the inner surface of the margin of the cornea.

4. The movement of the lens by means of the ciliary processes, or the zonula ciliaris, was assumed as the cause by Kepler, Scheiner, Porterfield, Camper, and many others.

5. Lastly, the influence of the muscles upon the form of the eye has been regarded as the cause of the internal change of adjustment by many writers, as Rohault, Bayle, Olbers, Home, and Schroeder van der Kolk, some of whom ascribe the influence in question to the m. recti, others to the m. obliqui.

That a connection exists between the movements of the iris and the action of the eye, by which it accommodates itself to vision at different distances, cannot be denied; for, when distant objects are viewed, the pupil becomes dilated, when near objects, contracted: and, notwith-

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* A full account of all the hypotheses relative to this subject is given by Haller, Element. Physiol. t. v. L. xvi. Sect. 4. § 20; by Olbers, loc. cit.; and by Treviranus in his Biologie, Bd. vi. p. 512.

.ding the continued presence of a strong light, as of a lamp held re the eye, the size of the pupil may be very much modified at by looking at objects at different distances; in doing which we se the axes of the eye to converge while we regard the near object, , on the contrary, give them a more parallel direction while a very nt object is the subject of our vision. These changes in the state he iris are, however, merely associate movements, consequent on nervus motorius oculi exerting an influence upon the ciliary or icular ganglion and the ciliary nerves, while it excites the action of muscles of the eye-ball. Contraction of the iris always ensues as a lt of associate or consentient nervous action, when even one eye only other being closed) is turned inwards, or inwards and upwards, is in this way associated with the voluntary action of several mus- supplied by the third or motor oculi nerve. In these phenomena, efore, we can recognise no immediate connection between the ions of the iris, and the power of the eye to accommodate itself to rent distances. But it remains to inquire how far distinct vision at rent distances can be explained by these movements of the iris.

Mile (*Magendie's Journal de Physiol.* vi. p. 166,) finds an expla- on of the accommodating faculty of the eye in the motions of the and the inflexion of the rays of light by its margin. The defect of theory is, as pointed out by Treviranus and Volkmann, that it sup- s a small proportion only of the rays to be employed in the forma- of the image,—those, namely, which pass close to the margin of the —while the greater mass of the light is not taken into account; and ever that the foci resulting from the meeting of the rays at other ts are not noticed.

Pouillet's theory is based, not upon the inflexion of the rays by nargin of the iris, but upon the different focal distance of the central peripheral rays; the first of which, being refracted by the central er portion of the crystalline lens, are, he supposed, brought to a s sooner than the latter, which pass through its marginal portion.

objection to the theory of Pouillet arises, that while the eye is l upon the more distant object and the pupil dilated, the central , notwithstanding the distinctness of the image formed by the peri- al rays, cannot be wholly without effect; and, if this be the case, ause of distinct vision at different distances cannot be what Pouillet s.

This objection is of equal force against the view proposed by Tre- ius, who admitted the change in the size of the pupil to be a cause, ributing with the varying density of the lens to effect the accommo- n of the eye.

all hypotheses which regard the accommodation of the eye to dis- es as a direct effect of the motions of the iris, we may, lastly, object Volkmann, that any change in the size of the pupil produced by tion of the light ought, in that case, to disturb the state of adapta- of the eye: which is not in accordance with facts.

e hypothesis that the adjustment of the eye is effected by a change e convexity of the cornea, appears to be sufficiently refuted by the lations of Olbers; for the compression of the eye by the action of its muscles is not capable of producing changes in the length of the radius of the surface of the cornea to the extent of 0·273 or 0·333 of an inch.

Home and Ramsden maintained, it is true, that they had observed such changes in the living eye during the vision of near and distant objects; but Dr. Young was unable to verify this observation, and it would be impossible to determine the reality of such a change accurately by experiment, on account of the mobility of the eye. The best means of ascertaining this fact would be to observe whether small images reflected by the cornea, such as the image of a light window, change their size and position while the eye is adapting itself to the perception of point-like objects situated at different distances in the same line.

The view which attributes the adjustment of the eye to the alteration of its form by the action of the external muscles, is also not free from objections. The phenomena of vision at different distances are certainly explicable on such a view; but that does not prove its correctness, for there are many different ways in which these phenomena might possibly be produced. The action of the straight muscles can, as Treviranus remarks, scarcely be conceived capable of producing elongation of the axis of the eye in the manner Olbers supposes. He imagines, namely, that by the action of these muscles the vitreous humour is compressed, and made to extend itself anteriorly and posteriorly. But the tendency of the straight muscles is merely to retract the eye, and, if resistance were afforded by the cushion of fat behind it, to flatten rather than elongate it; their action would therefore have the effect of adapting the eye to the vision of distant objects only, the image of which is formed nearer the lens than that of near objects; while it is in looking at very near objects, on the contrary, that we are conscious of an effort within the orbit. The compression and elongation of the eye might much more easily be effected by the oblique muscles; and Le Cameus, Rohault, and Schroeder van der Kolk have thus explained the accommodation of the eye. This view is in accordance with the circumstance that in the vision of near objects the axes of the eyes necessarily converge, to which movement the oblique muscles would contribute, as Luchtman has very ingeniously shown.* But this, as well as every other theory which attributes the adaptation of vision to distance to the action of the muscles of the eye, is open to objections. The state of adaptation of the eye can be entirely changed in a very short space of time by the local action of narcotics, the pupil becoming at the same time much dilated.

If the hypotheses already considered be rejected, there will still remain those which place the means of accommodation to distances in the interior of the eye,—namely, in a change of position or form of the lens by the action of the ciliary processes, or zonula. Although these latter hypotheses cannot be directly refuted, they are equally incapable of proof; and such, in fact, is the state of the question generally; the phenomena may be explained in very different ways, but no one explanation can be proved to be more correct than another. Under these circumstances it will be more judicious to direct attention to some important facts, which are not taken cognizance of in any of the views above mentioned, and which, though they do not disclose to us the cause of the self-adjusting faculty of the eye, show its intimate connection with other phenomena. The inquires which I instituted in the year 1826 relative to double and single vision, led me to notice the connection which subsists between the changes of adaptation to distances and the movements of the eye-balls themselves, by which their axes are altered in direction; a connection as intimate as that between the changes of adaptation and the movements of the iris, or that between the movements of the iris and the movements of the axes of the eyes.

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* Luchtman, De mutatione axis oculi secundum diversam distantiam objecti.—Trajecti ad Rh. 1832.

arly all the writers who have treated of the accommodation of the
to distances, have overlooked this important circumstance. Porter-
d was, as Volkmann shows, the only one of the older physiologists
uainted with these phenomena.

rom various facts on this subject it appears that change in the incli-
ion of the axes of the eyes towards each other induces a change in
refractive power of the eye, by which this organ is accommodated
he distance of the object, even when one eye only, which is closed,
rs its inclination towards the other, which is open. The same is
case with the motions of the iris: if one eye be fixed upon a given
nt, and the other eye closed, when the latter is moved, the size of
pupil even of the open eye undergoes a change proportionate to the
ree of convergence of the two axes of vision, giving the appearance
voluntary influence over the motions of the pupil (see pages 534–5).
movement of the iris simultaneously with that of the axes of the
s we have regarded as an associate or consensual movement, since
observed to occur only when muscles supplied by the third or motor
li nerve are in action, and that nerve is known to be the motor nerve
he iris, to which it sends filaments through the medium of the ciliary
glion. In the same way the adjustment of the eye to vision at
erent distances may be an associate movement connected with the
on of the muscles which draw the eye-ball inwards, and dependent
er on an organic connexion in the nervous system, or on the influ-
e of habit. The associate movement of the iris with the eye-balls
scarcely, however, be the result of habit.

slight influence upon the adaptation of the refractive power of the
can be ascertained by the will, without the direction of the axes of
eyes being necessarily changed; and this circumstance is itself a
of that the connection between the two is not essential, and that the
is not the constant cause of the other.

When the perception of an object is voluntarily rendered indis-
t without the direction of the axes of vision being changed, the iris
forms the usual motions, dilating when the eye is adapted for more
ant vision, and *vice versâ*. This is an example of nearly perfect
ntary motion of the iris, inasmuch as here the motion is, at all events,
associated with any voluntary movement of the eye itself inwards
upwards. (*Müller's Archiv.* 1837, p. cl.)

Ve perceive in this fact, as in all the phenomena previously de-
bed, the existence of an intimate connection between the motions of
iris and the power of modifying the refractive action of the eye;
, nevertheless, we are not justified in ascribing to the motion of the
even an indirect influence on the refractive power. It has been
posed that the motion of the iris may have an influence upon the
ry body or processes, and through their medium upon the position
he lens, by virtue of the firm connection of the ciliary body with
outer circumference of the posterior surface of the iris. This hypo-
is, however, is easily refuted; for the movements of the iris may be
ited by the stimulus of light independently of the will, and the same
ect appears to us equally distinct, whether it be illuminated with a
ht light, when the pupil will be proportionally contracted, or the eye

screened from the action of light, when the pupil will be dilated. (Compare *Volkmann*, loc. cit. p. 156.) It appears, therefore, must probable that the faculty of the eye which enables it to adjust itself to different distances depends on an organ which has certainly a tendency to act by consent with the iris, but yet is in a certain degree independent of it. Reasoning *per exclusionem*, it is certainly most probable that the ciliary body has this motor power, and this influence on the position of the lens, but we have no positive proof of its possessing contractility.

The self-adjusting faculty of the eye is, according to the observations both of Dr. Young and Volkmann, impaired by the extraction of the lens in the operation for cataract.

V. OF MYOPIA AND PRESBYOPIA, OF THE MEANS OF REMEDYING THESE DEFECTS OF VISION, AND OF THE USE OF GLASSES.

"Myopia," near-sight; and "Presbyopia," far-sight.—Spectacles and Optometers.—Many persons have not the power of accommodating their eye to vision at different distances, or have in it so slight a degree as to distinguish objects at a certain distance only; such persons are said to be either short-sighted or long-sighted. To individuals in this condition it is, of course, impossible to prove that the eye has the faculty of adjustment to distance; and this may have been the cause of the skepticism of Treviranus and others. Near-sightedness is most frequently observed in the middle period of life. Long-sightedness is more common in old age. The cause of these defects of vision is very often supposed to lie in the refracting media of the eye, as in the form of the cornea; and the cornea is, in fact, less convex in old age than in youth; but the convexity of the cornea is greatest in childhood, and, nevertheless, as Volkmann remarks, children are not frequently subjects of "near-sight." Myopia and presbyopia may with more reason be attributed, as regards their immediate cause, to want of the power of adjustment, or to great feebleness of this muscular act. With such a condition the eye would necessarily see objects distinctly at that distance only to which the form of its refractive media is best adapted. A strong proof of imperfection, or loss, of the power of adjustment being the cause of myopia, and presbyopia, is the circumstance that shortsightedness may be acquired merely by habitually using the eye for the perception of near objects only, and neglecting distant vision. Thus, children become short-sighted from accustoming themselves to read or write with the face too close to the paper. The constant use of the microscope may give rise to short-sightedness, and often does induce it as a transient condition lasting a few hours. The wearing of spectacles also is injurious in this respect, since they disuse the eye to self-adjustment for distinct vision at different distances.

We may, in a few words, explain the action of spectacles in aiding vision in persons labouring under myopia and presbyopia. The presbyopic, or long-sighted eye, is aided by a convex glass; the myopic, or short-sighted, by a concave glass. In the long-sighted eye, rays from distant objects are brought to a focus upon the retina; but the rays from objects less distant, or very close to the eye, not being made to converge so rapidly, meet behind the retina. A convex glass corrects this defect by causing the rays emitted by near objects to intersect each er at a point nearer the lens,—namely, in the retina itself. In the rt-sighted eye the reverse condition subsists. The rays from near ects here meet in the retina, and produce a distinct image; but the s of distant objects, which are more easily brought to a focus than se of near objects, meet before the retina, and form undefined spectra n it. The concave glass corrects this by causing the rays to become re divergent, and therefore less readily concentrated by the eye to a ıs, which is thus made to fall upon the retina.

'he use of the optometer to determine the mean distance of vision which the eye of any individual is adapted, is founded upon the expe- ent of Scheiner, mentioned at a preceding page. It consists in ascer- ing the distance from the eye at which a small object viewed with eye through two openings in a card, separated by a less distance n the diameter of the pupil, appears single; or the distance from the at which the double images of a thread, viewed without effort ough two openings in a card, cross each other or unite to one image. Young's Optometer.) The distance thus ascertained is the mean gth of vision of the eye. Before and behind this, an object viewed ough the two openings in the card appears double; that is to say, its ge falls either before or behind the retina. The application, how- r, of this method is always very imperfect, on account of the diffrac- of the rays at the margins of the small openings in the card.

ifluence of convex lenses upon the distance of distinct vision.—We have next to con- r the action of glasses which increase the size of the image by altering the ance of distinct vision. The simplest kind of glass which has this effect is the mon lens, or simple microscope. If a small object be brought very near the eye, ppears very large, but is wholly indistinct, because the point towards which the from it are made to converge lies behind the retina. The action of a lens inter- d between the object and the eye is to shorten the focal distance of the image. If lens be properly placed, so that the image falls upon the retina, all the details of orm are seen distinctly, while it appears of the same magnitude as when held close e eye without the lens. In this case the increase of size is the result of the close roximation of the object; and the lens merely gives distinctness, which the image near an object would not otherwise have. In the telescope and compound micro- e the image is formed, not in the eye itself, but in front of it. The rays meeting rm the image, not being received there by any opaque surface, diverge again from point, in the same way as if the object from which they originally radiated were e situated. On this condition depend both the increase of size and the distinctness e image in the eye; for an image near the eye is seen under a greater angle than more distant object. And if the image occupies the situation of distinct vision at t inches, it is not only increased in size, but has the distinctness of objects gene- y viewed with the naked eye at that distance. Telescopes serve to increase in , and render distinct, the image of very distant objects; microscopes to enlarge, render distinct, the image of near objects. The number of glasses employed in e instruments is very various. A second glass, placed behind the first, may either lify the image and its situation, or, if the image is already formed by the first glass re the rays traverse the second, this image stands in the relation of an object to second glass. The image formed by the second glass may be still further modi- by a third glass, or may become an object to it. The glass which receives the of light directly from the object itself is called the “object glass;” the glass next he eye is the “eye-piece,” or “ocular.” In the microscope, the image formed by or more lenses is viewed by means of the ocular, just as an object is viewed with mple lens. The brightness of the image depends on the quantity of light which object-glass receives from the object, or which, in the microscope, is thrown by ficial illumination upon the object. According as the quantity of light which goes rm the image in the telescope or microscope is greater or less than that which the ed eye receives from the object, will the image of the object be more or less vivid than when seen without the instrument. The image of objects viewed with the telescope is brighter than the object appears when viewed with the naked eye; because the object-glass of the telescope receives from the object, and applies to the formation of the image, more light than the pupil of the naked eye can admit.

VI. OF THE CHROMATIC AND ACHROMATIC PROPERTIES OF THE EYE.[*]

a. Chromatic lenses.—Although the rays from a luminous object are by the refractive power of a lens concentrated so as to form a distinct image upon any surface, when spherical aberration is avoided, yet the image is not perfect unless the rays of light are homogeneous, that is, of one simple colour; for, even though spherical aberration be avoided, it is quite impossible, without further means, to bring the heterogeneous rays of white or mixed light to one focal point, since the different-coloured rays of white light have different degrees of refrangibility, and, therefore, with the same refracting medium have a different focal distance.

The image formed by a convex lens is at the proper focus very slightly coloured: the outline of a white image received upon a dark ground has merely a margin of purple, which is scarcely perceptible; but, in proportion as the surface which receives the image is moved from the focal point, the more marked becomes the fringe of colours, in addition to the increasing indistinctness of the image formed by the white light itself. (See *Kunzek*, *Die Lehre vom Lichte*, p. 157; and *Tourtual*, loc. cit.)

b. Achromatic lenses.—The dispersion of the coloured rays by a prism is counteracted by a second prism of the same refractive and the same dispersive power. Two prisms conjoined form a refracting medium with parallel surfaces, from which the rays of light transmitted through it will issue at the same angle as they entered, just as in passing through a plane plate of glass. Dollond, however, discovered that the dispersive power of media is not always proportionate to their refractive power; and that there are media which have a strong refractive action on light, but little dispersive influence. Flint-glass refracts light more strongly than crown-glass, but its excess of dispersive power is still greater. This led to the construction of achromatic prisms by the combination of prisms of unequal refractive and dispersive power.

c. Achromatic property of the eye.—The human eye is achromatic as long as the image is received at its focal distance upon the retina, or as long as the eye adapts itself to the different distances of objects. The cause of this achromatic property cannot with certainty be determined, although it is easy to show that the optical structure of the eye may very possibly give this property. The refractive media of the eye are of unequal refractive power, both as regards their convexities and their chemical constitution. The lens has two unequally convex surfaces, and the cornea and aqueous humour form a refracting medium of unequal chemical constitution. The cornea and aqueous humour taken together form a concavo-convex lens, the refractive power of which is different from that of the crystalline lens. The dispersive co-operation of the sensorium in the act of vision. To these belong not merely the act of sensation itself, and the perception of the changes produced in the retina, as light and colours, but also the conversion of the mere images depicted in the retina into ideas of an extended field of vision,—of proximity and distance,—of the solidity (in the geometrical sense) and size of objects. To this class of phenomena belong also the effects of the reciprocal action of different parts of the sensitive apparatus on each other, and many phenomena in the retina either not excited by light at all, or not by its immediate action. These different phenomena might be treated of under the following heads: 1. Of the action of the retina generally, and of the co-operation of the sensorium in vision. 2. Of ocular spectra. 3. Of the reciprocal influence of different parts of the retina upon each other. 4. Of the simultaneous action of the two eyes. 5. Of the subjective phenomena of vision.

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[*] J. Müller, Physiol. des Gesichts-sinnes, pp. 295, 414.—Tourtual, Die Chromasie des Auges; Meckel's Archiv. 1830, p. 129.

1. *Of the action of the retina generally considered, and of the co-operation of the sensorium in vision.*

Action of the retina and sensorium.—It has been shown already, in the Preliminary considerations on the Physiology of the Senses, that the retina is not a mere conductor of external impressions, but itself reacts against these impressions. Light and colour are actions of the retina, and of its nervous prolongations to the brain. The kind of colour and luminous image perceived depends on the kind of external impression. With this property of the retina, by virtue of which it becomes when irritated the seat of the sensations of colour and light we are so well acquainted, that we found upon it all inquiries concerning vision. The vibrations of a fluid existing in all space, the ether, when of a certain rapidity, produce in the retina the sensation of a certain colour; when of a different degree of rapidity, that of another colour; these colours or sensations being modes of reaction of the retina. The simultaneous impression of undulations of different rapidity upon the same points of the retina excites the sensation of white light. These same sensations of colours and light may, however, be produced, without the agency of the vibrations of an ether, by mere irritation of the retina by means of electricity or mechanical pressure.

If it be the change produced in the retina which we perceive in vision, we may with equal correctness say that in the act of vision the retina feels itself in a particular state, or that the sensorium perceives the retina in a particular condition. The condition of repose of the retina is the cause of the appearance of darkness before the eyes; the active state of the retina is the cause of the sensation of the illuminated field of vision. Under certain circumstances we see our own retina, and separate parts of it, when no images are produced in it by external objects. Besides the spectra produced by pressure and electricity, we have an instance of this in the following interesting phenomenon first observed by Purkinje:—If, in a room otherwise dark, a lighted candle be moved to and fro, or in a circle, at the distance of six inches before the eyes, we perceive, after a short time, a dark arborescent figure ramifying over the whole field of vision; this appearance is produced by the vasa centralia distributed over the retina, or by the parts of the retina covered by those vessels. There are, properly speaking, two arborescent figures, the trunks of which are not coincident, but on the contrary arise in the right and left divisions of the field, and immediately take opposite directions. One trunk belongs to each eye, but their branches intersect each other in the common field of vision. The explanation of this phenomenon is as follows:—By the movement of the candle to and fro, the light is made to act on the whole extent of the retina, and all parts of the membrane which are not immediately covered by the vasa centralia are feebly illuminated; those parts, on the contrary, which are covered by those vessels cannot be acted on by the light, and are perceived, therefore, as dark arborescent figures. In most persons this experiment succeeds readily; but in some individuals the phenomenon is produced with difficulty, or not at all. The figures of the vessels appear to lie before the eyes, and to be suspended in the field of vision. We have here a distinct demonstration of the axiom, that in vision rceive merely certain states of the retina, and that the retina is itself the field of ,—dark in the unexcited, illuminated in the excited condition.

e of the most difficult problems in physiology is that relative to the respective nce of the retina and sensorium in vision. This department of the physiology e senses may be correctly styled the metaphysical, since we are at the present totally destitute of any empirical means of elucidating it. The question to be mined is the following:—Where is the state of the retina perceived; in the retina , or in the brain?

al size of the field of vision.—The actual size of the field of vision depends on the t of the retina, for only so many images can be seen at any one time as can oc- the retina at the same time; and thus considered the retina, of which the affec- are perceived by the sensorium, is itself the field of vision. But to the mind of dividual the size of the field of vision has no determinate limits; sometimes it rs very small, at another time very large; for the mind projects the images on tina towards the exterior, the cause of which will be explained hereafter. Hence ental field of vision is very small when the sphere of the action of the mind is d by impediments near the eye; on the contrary, it is very extensive when the ction of the images on the retina towards the exterior by the influence of the mind impeded. The mental field of vision is very small when we look into a hollow of small capacity held before the eyes; it is large when we look out upon a land- through a small opening; it is more extensive when we look at the landscape gh a window; and most so when our view is unconfined by any near object. In ese cases the idea which we receive of the size of the field of vision is very dif- t, and, nevertheless, its absolute size is in all the same, it being dependent on the t of the retina; for, as was before said, we cannot see at one time more than the t of the retina is capable of containing. Nevertheless, although in looking upon dscape through an opening, the whole image of the scene is not larger than the mference of the opening through which it is viewed, and occupies the same space the retina; yet the idea conceived of it is extremely different. Hence it follows he mind is constantly co-operating in the acts of vision, so that at last it becomes ult to say what belongs to mere sensation, and what to the influence of the mind. ult age it would only be by abstracting the action of the mind from the process ion that we could obtain the mere sensation of vision, as it is perceived possibly new-born child; for the child which has as yet no idea of proximity and dis- , would necessarily recognise no difference in the size of the field of vision, her it looked into a tube closed at one end, or through an open one upon an ex- ve landscape. This consideration leads us also to the conclusion, that the simple ption of the images of objects must be an original faculty, quite independent of eas derived from them.

ages of the individual's own body in the field of vision.—Certain parts of our body y constantly occupy a part of the field of vision, and therefore have a share in the which the sensations of vision excite in the mind. When we look with one eye one side of the field of vision is occupied by the image of one side of the nose. e depress the eye-brows, the upper part of the field of vision becomes occupied em. If the cheek be raised, a part of it is seen at the lower part; and if the outer on of the orbicularis palpebrarum muscle be contracted, a shadow thrown by the tments of the eye is seen at the outer part of the field of vision.

though the images of our body perceived by the sense of vision are merely images ted on the retina, and by it communicated to the sensorium, they are confidently preted, like the images of external bodies, as real objects. The image of our , which we see, is not, in point of fact, our hand, but only its representation in retina. When we grasp any object, the movement is represented in the retina: ee that we grasp the object, for the image of our hand is seen to grasp the image e object. We are also made acquainted with the performance of the act by means nother sense, namely, by sense of touch in the hand, and the sense of movement . It appears an extraordinary circumstance that, although the perception of any of our body by the sense of common feeling or touch, and by the sense of vision, s place in such different localities, the two sensations never interfere with each r; they are brought into harmony and unison through the influence of the mind. t this is the case we can render evident to ourselves by an example in which the rence of locality is still more striking, and where nevertheless the two sensations y the power of the mind not less closely brought into unison.

If while we look at our image in a mirror we move our hands, we are informed of those movements, as well by the sense of feeling as by the image in the mirror; and, although the seat of impressions on the senses of touch and sight is so different, we derive from them through our mental agency but one harmonious idea.

Inverted images and erect vision.—In accordance with the laws of optics, the images are depicted on the retina in an inverted position as regards the objects themselves; what in the object is above, is in the image represented below, and *vice versâ;* the right side of the object is to the left, and the left side to the right; while the relative position of its different parts remains precisely the same. The question now arises, whether we really see the images inverted, as they are in the retina; or erect, as in the object itself. Since the image, and the affected parts of the retina, mean the same thing, the question physiologically expressed is this: Are the minute divisions of the retina affected in vision perceived by the sensorium in their natural relation to the object?

The view which I take of the question, and which I proposed in my work on the physiology of vision, is, that even if we do see objects reversed, the only proof we can possibly have of it is that afforded by the study of the laws of optics; and that, if everything is seen reversed, the relative position of the objects of course remains unchanged. It is the same thing as the daily inversion of objects consequent on the revolution of the entire earth, which we know only by observing the position of the stars; and yet it is certain that, within twenty-four hours, that which was below in relation to the stars, comes to be above. Hence it is, also, that no discordance arises between the sensations of inverted vision and those of touch, which perceives everything in its erect position; for the images of all objects, even of our own limbs, in the retina, are equally inverted, and therefore maintain the same relative position. Even the image of our hand, while used in touch, is seen inverted. The position in which we see objects, we call therefore the erect position. A mere lateral inversion of our body in a mirror, where the right hand occupies the left of the image, is indeed scarcely remarked; and there is but little discordance between the sensations acquired by touch in regulating our movements by the image in the mirror, and those of sight, as, for example, in tying a knot in the cravat. There is some want of harmony here, on account of the inversion being only lateral, and not complete in all directions.

Volkmann agrees with this view of the question. He also argues that no explanation of erect vision is required, as long as all things equally, and not some objects only, appear to the eye inverted. Nothing can be inverted where nothing is erect; for each idea exists only in antithesis to the other.

Of the "subjective" phenomena of vision.[*]

If we exclude from consideration those phenomena affording evidence of action of the retina, which are in some way dependent on the influence of the external light, such as the "ocular spectra," and the phenomena of double vision and the radiation of sensation in the retina, ı still remain many others which are dependent on causes of a very rent nature. The most remarkable of these phenomena, for a vledge of which we are principally indebted to Purkinje, are the wing:—

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[*] Purkinje, Beobachtungen und Versuche zur Physiologie der Sinne: i. Prag. 1823; ii. Berlin, 1825.

ppearances produced by pressure on the retina.—The luminous arances produced by pressing with the fingers upon the eye (named urkinje "Druckfiguren") vary in form; they are sometimes annular, ıtimes star-like, and sometimes regularly divided into squares; nce Purkinje compared them to the figures produced by sonorous ations. When a plate of glass covered with water is struck with ow of a violin, the plate not only divides into vibrating segments, parts which remain at rest, but the water upon the vibrating parts e glass presents a most regular distribution into rhombic figures or onary waves. The figure in the eye calls to mind the appearance ecussating waves.

he vascular figure, described at page 738, is sometimes seen with minous character.—It was sometimes seen thus by Purkinje as the t of pressure, particularly in the morning; and I have frequently this luminous ramified figure in the dark field of vision, when, after nding a flight of stairs, I have found myself suddenly in a dark e, and also when I have suddenly immersed my head in bathing. luminous appearance is evidently the effect of the pressure of vessels filled with blood upon the retina.

uminous appearance produced by the arterial pulse.—When the l is congested with blood, it is easy to perceive that each beat of the e is attended by a change in the degree of light perceived by the ı, by a pulsating illumination of the field of vision. This phenoon is very easy to observe. Some few times I have seen a similar ıge in the field of vision, or a rhythmic appearance of a small bright , in the middle of the dark field of vision, isochronous with the reation and the corresponding movement of the brain; but this pheenon cannot be excited at will, and has presented itself to me only w times.

isible movement of the blood.—There are many circumstances er which a general expression of the circulation is perceptible. It is ı, however, more particularly in looking at surfaces which are brightluminated, but not to a dazzling degree, as the sky; or after fixing eyes for some time upon a surface of snow or white paper. The earance consists in an indistinct confused movement, as of points sing each other in all directions, or like the motion of vapours. appearance is so undefined, that the direction of the movement not be determined. It evidently is due to the motion of the blood. he same nature is the much more definite appearance of dark bodies ı tails, flying and moving about in all directions, which is seen somes by persons suffering under plethora, or congestion of blood in the d, on rising suddenly from the stooping posture. The sensation of creeping over the surface is an analogous affection of the nerves of ımon sensation or touch.

uminous circles seen in the dark field of vision on a sudden latemovement of the eyes.—This appearance is a constant result of suddenly turning the eyes to either side when in the dark. Two circles of light are always seen; they must therefore be produced by an affection of the retinæ at two different "non-identical" points,—perhaps, at the situation of the entrance of the optic nerve into each eye.

Appearances produced in the eye by electricity.—These phenomena have been investigated by Ritter, Purkinje, and Hjort. If the eye be made to form part of a galvanic circle,—one pole, for example, being applied to the conjunctiva of each eye-lid,—an appearance like a flash of lightning will be perceived when the circle is either closed or interrupted. The same thing takes place also when, although the eye does not lie in the direct line of the electric current from pole to pole, the electricity is nevertheless in part directed towards the eye; as when one pole of the battery is, for instance, applied to the lower eye-lid, and the other to the mucous membrane of the mouth. Even a simple pair of plates of zinc and copper are sufficient to produce the appearance above mentioned in a dark room. A small battery excites more remarkable phenomena: according to Purkinje's experiments, a yellowish light is seen at the zinc pole, a violet light at the copper pole. Under certain conditions, which Purkinje details, peculiar appearances are produced at determinate points of the field of vision corresponding to the situation of the optic nerve, and to the central point of the retina.

Spontaneous appearances of light in the darkened eyes.—If we direct our attention to what takes place in the eyes when closed, not merely do we see sometimes a certain degree of illumination of the field of vision, but also occasionally an appearance of light developed in greater intensity: sometimes, indeed, this luminous appearance spreads from the centre to the circumference, in the form of circular waves, disappearing at the periphery. At other times the appearance has more the form of luminous clouds, nebulæ, or spots; and, on rare occasions, it has been repeated in me with a regular rhythm. Closely connected with these more indefinite appearances in the eye are the more distinct forms seen at the time of falling asleep, or in the period that precedes this, which are due to the action of the mind isolating different definite forms in succession from the cloud-like appearances in the eye, "the chaos of dreams," according to Gruithuisen.

Opposed to these phenomena is the transitory loss of sight, accompanied by the appearances of a mist, coloured smoke, or similar phenomena, before the eyes, which sometimes occurs in persons with a weak nervous system, and which is a state of temporary exhaustion of the retina A person in perfect health may indeed induce this phenomenon, by looking for a very long time at a white or coloured surface.

Flickering before the eyes after taking narcotic substances.—Digitalis is most prone to produce this symptom. Purkinje has instituted observations upon it in his own person. If the action of the narcotic is strong, definite forms appear.

Apparent movement of objects consequent on repeated rotation of the body.—This phenomenon has been already described at page 639. It must be distinguished with respect to its cause from the apparent movements seen after looking at objects really moving; which arise from the successive disappearance of the spectra left by the moving

a. The apparent motion produced by the former cause occurs though the eyes were closed during the rotation of the body.

fect of the sense of colours.—Owing to an original disposition of etina, many individuals have in an imperfect degree only the power stinguishing colours. From numerous observations made on such ons, the younger Seebeck (*Poggendorf's. Annal.* 42,) has obtained following results:—Besides those persons who find difficulty in rmining the colours of objects generally, without however mistaking colour for another, there are many individuals who are in a more s complete degree incapable of distinguishing perfectly dissimilar ırs from each other. But these persons differ, again, not only in legree of their defect, but also in its character. Hence Seebeck has led them, smaller differences being disregarded, into two classes. he first class belong those who, though differing considerably in the ee of their imperfection of vision, agree pretty nearly in the circumce of confounding the following colours:—

1. Light orange and pure yellow.
2. Intense orange, light yellowish green, or brownish green, and yellow-brown.
3. Pure light green, grey-brown, and flesh-colour.
4. Rose-red, green (rather blue than yellow), and grey.
5. Crimson, dark green, and hair-brown.
6. Bluish green and imperfect violet.
7. Lilac and bluish grey.
8. Sky-blue, grey-blue, and grey-lilac.

he individuals of this class have a very imperfect power of distinhing the impression of colours generally; but the defect is greatest regard to red, and the complementary colour green; these colours g to them scarcely or not at all distinguishable from grey: the colour which the perception is next in degree defective is blue, which is erfectly distinguished from grey. The perception of yellow is the t perfect, though objects of this colour also are distinguished from a urless surface much less easily than by the eye in its normal state. dividuals belonging to the second class likewise recognise yellow ; red is distinguished better, blue less perfectly, from the absence of ur, than in persons of the first class: but the distinction of red from is above all more imperfect here. The colours which they cond are as follows:—

1. Light orange, greenish yellow, brownish yellow, and pure yellow.
2. Bright orange, yellow-brown, and grass-green.
3. Brick-red, rust-brown, and dark olive-green.
4. Cinnabar-red and dark brown.
5. Dark carmine and blackish blue-green.
6. Flesh-red, grey-brown, and bluish green.
7. Dull bluish green and (somewhat brownish) grey.
8. Imperfect (somewhat yellowish) rose-red and pure grey.
9. Rose-red, lilac, sky-blue, and grey (including lilac).
10. Crimson and violet.
11. Dark violet and dark blue.

It is the perception of the least refrangible rays only that is here very imperfect, which is not the case in persons of the first class.

We must distinguish from the subjective phenomena of vision the images of objects existing in the interior of the eye, and throwing a shadow upon the retina. Such are the thread-like convoluted figures in which rows of globules appear to be contained. These figures are not fixed; not only do the separate parts of the figures alter their relative position, but the whole figures change their place in the field of vision. By an energetic movement of the eyes we can cause them to shift their place somewhat to the side or upwards, but they soon return to their original situation, and, after having previously risen, they gradually sink again. Many persons have such figures in considerable number before their eyes, but those in the middle of the field of vision only are seen distinctly. In microscopic observations they often lie in front of the object, and interfere with the perception of it; in such a case I am in the habit of displacing them, by pressing on the eye at the side. In many individuals these appearances are not seen, while to others they are very troublesome. They are by some writers called muscæ volitantes, and confounded with certain symptoms which accompany the development of amaurosis; but they are quite innocent in their nature, and exist in persons whose powers of vision are most acute. I have been subject to them from childhood. Whether they be owing to particles floating in the aqueous humour, or contained in the vitreous body, is not known.

SECTION II.

OF HEARING.

CHAPTER I.

Of the physical conditions essential to hearing.

A MECHANICAL impulse upon the organ of hearing excites in the auditory nerve the sensation of noise, or sound; and, if the impulse be rapidly repeated at regular intervals, a musical tone is heard, the acuteness of which is proportionate to the number of the impulses imparted to the nerve within a given time. Musical tones are most frequently produced by the vibrations of elastic bodies. The sounds produced by the separate impulses of the teeth of a saw, or of the wheel in Savart's experiments, or by the impulses of the water in the siren of Cagniard La Tour (see page 688), give rise, by their quick succession, to a continuous tone. From a vibrating elastic body which makes one thousand vibrations in a second, if we reckon the movement towards both sides, the organ of hearing receives five hundred impulses in a second, propagated to it by the air or other soniferous medium. The effect of these vibrations is the same as that of five hundred direct impulses of a body which does not produce sound by vibrations.

hether the tones be excited by vibrations or mere impulses, the agation both of the impulses and vibrations to the organ of hearing fected in accordance with the general laws of undulatory or vibra- motion.

e original production of the sounds which are due to vibrations is also regulated e same laws, a knowledge of which is consequently necessary in studying the iology of hearing.

I. *Of undulations in general.*[*]

hen the state of equilibrium of the different parts of any body has been disturbed external cause, the complete recovery of the previous state of repose is preceded movement in which the different parts of the body alternately approach the posi- f rest, and are removed from it. If a pendulum is driven towards one side, it nues to move in that direction until the moving force =0; it is then drawn down e force of gravity, falling with increasing rapidity, which prevents it from imme- ly resuming the state of rest, and causes it to ascend on the opposite side; and movements are repeated until the equilibrium is restored. Movements, in which arts of a body alternately approach and depart from the state of equilibrium, are l vibrations, oscillations, or undulations. *Undulations* are either undulations of ion, or flexion-waves, consisting in the surface of the body being thrown into ate elevations and depressions without any change in its density; or they consist essive condensations and rarefactions, without the form of the surface being ged. The rarefactions in this case correspond to the depressions of the undula- of inflexion. Vibrations or oscillations are either progressive, when they tra- the different parts of a body in succession; or they are stationary, in which case, hose of a pendulum, they do not change their place.

Undulations of inflexion, or elevation and depression, in incompressible fluids.—ndulations of inelastic fluids are disturbances of the equilibrium of their surface ertain depth. Gravity is the prime cause of this kind of undulatory movement. undulations in water are much too slow to give rise to sound. It is, however, rtant to become acquainted with their laws, since the laws of undulations gene- can be most easily observed in them.

ogressive undulations.—If the equilibrium of a fluid is disturbed at any one point, lar undulations with circular elevations and depressions are formed around this ; each undulation extending outwards from it, and being followed by another. stronger the impulse, the higher are the elevations of the waves, and the more is their motion; though this is also influenced by the depth of the fluid. If lations are excited in a fluid contained in a deep channel with parallel sides by pulse acting on the whole breadth of the fluid, their motion is progressive in a ht line, and they do not form circles moving from a centre. The motion of s is not produced by the progressive motion of the particles of water; on the ary, the water itself is stationary, the waves only move over its surface. The cles of water in the situation of a wave merely suffer a movement of rotation: in a hollow as the wave approaches them, they successively form the most ted part of it; the wave still moving onwards, they come gradually to form the ession behind the wave, whence they again rise as the next approaches.

when undulations meet from opposite directions, the elevation of one coincides the depression of the other, they neutralize each other, and the surface of the remains level; but, beyond their place of meeting, the waves again appear mov- nwards in their original direction.

hen parallel waves coming from different, but not directly opposite directions, sect each other, both the effects above mentioned are produced at different points. is the "interference" of waves.

aves are reflected by the surfaces of solid bodies; and in the case of a wave, as ray of light, the angle of reflection is equal to the angle of incidence. If a wave nagined to consist of a series of forces moving forwards side by side, each part e wave will be reflected by the solid surface at the same angle as that under

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E. H. and W. Weber, Wellenlehre; Leipz. 1825.—Eisenlohr, Lehrbuch der Physik; nheim, 1836, 121.

which it impinged on the surface, and thence will result a system of reflected portions of waves which will together form a reflected wave. The direction of the reflected wave may be either the same or different from that of the original wave. The reflected and incident waves have the same direction, when straight waves are produced in a channel, as above described, and when these waves impinge in a perpendicular direction on the reflecting surface, and also when circular concentric waves issuing from one point strike upon a surface which itself forms a concentric circle around that point; in the latter case the reflected waves move back again towards the central point whence they arose.

A circular wave or undulation is reflected from a plane surface in the direction which a wave would have, that issued from a point at the same distance behind the surface as the central point of the original wave lies in front.

Waves passing through an opening in any solid body do not retain the form which they had in the opening; on the contrary, their extremities which have passed the margins of the opening receive a circular inflexion around these margins, in consequence of which the waves, after their exit, not merely extend forwards, but also in the lateral direction. This is the "inflexion" of waves.

B. *Undulations of inflexion or flexion-waves in solid bodies.*—The cause of the undulations of this kind in fluids is the force of gravity; in solid bodies it is the force of cohesion and elasticity. These undulations are much quicker in solid bodies than in water, and in elastic bodies are the cause of sound.

If a stretched cord or string of a musical instrument is struck, not at its middle, but near one extremity, an extension of it is produced at this part, and is communicated as a wave or oscillation to the whole cord, travelling from one end to the other where it is reflected back again like the undulations of fluids.

If the cord or string is struck several times in succession, a regular series of undulations is produced, as upon the surface of water. The reflection of these undulations at the extremity of the cord, and the meeting of the incident and reflected undulations, give rise to the stationary vibrations; and the parts of the cord which remain at rest between these stationary waves or vibrations are the "nodal points."

The simplest stationary vibration of a cord or string is, however, that which results, not from the meeting of progressive undulations, but from the transverse vibration or movement from side to side of the whole cord between its fixed extremities, which here constitute the nodal points. This kind of vibration is induced most readily by striking a string with the finger, or with a violin-bow. The transverse oscillation of solid bodies which do not owe their elasticity to tension, such as metal rods fixed at one extremity only, is also an instance of stationary vibration.

C. *Undulations of condensation in liquids, gases, and solid bodies.*—The undulations of inflexion in water are not attended with any condensation and rarefaction, nor are they necessarily so in a cord or string. If the cord is not extensile, or not elastic, the undulations of inflexion may be produced by the mere displacement, and the striving of the parts of the cord to regain the straight direction. Generally, however, the waves of inflexion in strings are attended with alternations of condensation and rarefaction. The peculiarity of the undulations of inflexion consists in many parts of the body having imparted to them so considerable a movement in the direction perpendicular to its surface, that the form of the surface undergoes a visible change.

Undulations excited in the air consist of progressive condensations and rarefactions. The part where the condensation exists is analogous to the elevation; that where the rarefaction is, to the depression of an undulation of inflexion. A progressive undulation travelling through a column of air in a tube is reflected at the extremity of the tube if this is closed, and its retrograde course retains its original properties. The wave is also imperfectly reflected even when the extremity of the tube is open; but, experience has shown that in that case the properties of the undulations are reversed, its rarefaction taking place where its condensation should be, and *vice versâ*. Undulations in the open air have a spherical form. (*Weber*, op. cit. § 276.)

II. *Of the stationary and progressive undulations of sonorous bodies.*

The vibrations of sonorous bodies are either undulations of inflexion, or undulations of condensation. Either of these kinds of undulations, or both simultaneously, may take place in strings and solid bodies which give sound. Columns of air, in yielding sound, are the seat of undulations of condensation only. The undulations of sonorous bodies may be either stationary or progressive.

e rate of the vibrations of stretched strings, or the number of the impulses which impart to the air, increases in an inverse ratio with their length, and in a direct with the squares of the extending forces. Thus a string which performs one red vibrations in a second of time, if reduced to half the length, will vibrate undred times in the same period, the extending force being equal; or, its length ining the same, if it performs one hundred vibrations with an extending force of oth [half an ounce], it will vibrate two hundred times when the extending force s four loth, four hundred times when the extending force is sixteen loth.

norous rods are also susceptible of stationary vibrations, the number of which in en time will be in a direct ratio with the thickness of the rods or bars, and in an se ratio with the squares of their length.

der certain circumstances a progressive movement of the summit of the undula- is combined with a stationary transverse vibration, without any change in the ity of the transverse vibrations being thereby induced: for instance, when a g is struck near one of its fixed points, it not merely performs transverse vibra- , such as it makes when struck at its middle,—that is, transverse vibrations l in length to the whole length of the string,—but the summit of this stationary lation travels to and fro from one end of the string to the other, being reflected ich of its fixed points. The number of vibrations of a string thus vibrating is ly the same as that of a string the summit of whose vibrations remains constantly e middle; and as the acute or grave character of a sound, or its pitch, always nds on the number of vibrations performed within a certain time, the "pitch" of ote produced is in both cases the same, but the "tone" is somewhat different. is an important circumstance in relation to the theory of the "tone," or quality fferent sounds.

ationary undulations or vibrations are produced also when, by touching lightly a hed string, we give rise to a nodal point in that situation, and then strike the of the string thus isolated. If, for example, the string is touched at its middle, ither its upper or lower half then struck with the violin-bow, not merely does alf that is struck become the seat of transverse vibrations, but the other half also tes from side to side, though in the opposite direction. The number of the tions in a given time is in this case twice as great as when the string vibrates in hole length, and the sound produced is the octave of the fundamental note of the g. If the string is touched at the point of junction of its first and middle third, a l point is formed between its middle and last third also, and the number of the tions is three times as great as that of the vibrations of the entire string within ame period. In the same way, by isolating and striking a fourth or fifth of the g, a regular division of the string into four or five vibrating portions, separated odal points, is induced. Pieces of paper placed upon these nodal points during ibration of the string are not thrown off. The sounds resulting from the vibra- of a string thus divided by nodal points are called "harmonic notes."

oth stationary and progressive undulations of elastic bodies are adequate to the uction of the phenomena of musical sounds, if they are regularly repeated; for the stationary vibrations become progressive undulations when communicated to ucting media: each stationary vibration excites in the air, in water, or in solid es capable of conducting sound, a progressive undulation.

unds may be produced in solid bodies, as well as in columns of air in tubes, by ressive undulations of condensation. Rods may be thrown into longitudinal lations of condensation and rarefaction by friction in the longitudinal direction. e progressive undulations of condensation, without any transverse vibration, may wise produce sound in a stretched string.

vibrating string is prone to yield, besides its fundamental note, another fainter d, a harmonic of the other; as the fifth, or the third of the higher octave. The er sounds accompanying the principal sound of a bell are well known.

he column of air in pipes is susceptible of no transverse vibrations, but merely of progressive undulations of condensation, which travel to and fro along the length e tube. The blast is continuous; but the effect which it produces is intermit- . The number of undulations within a given time, or, what is the same thing, length of the undulations, is determined by the length of the column of air.

gentle blast gives rise to the fundamental note of a covered pipe, in which case nodal point lies at the extremity of the column of air. The same blast causes the development of a nodal point in the middle of the column of air in an open pipe, and the note produced is consequently an octave higher. By blowing with greater force, the column of air is made to subdivide itself still further, and higher notes are the result.

We have lastly to explain the difference which obtains between a mere "noise," a "report," a "continued sound not of musical character," a "musical sound," and "tone." Any impression upon the organ of hearing by an undulation, or several undulations, communicated to it, gives rise to a sound or noise. This sound, when produced by a single impulse, is short in duration; and, if intense, has the character of a "report." The intensity of the sound depends on the extent of the excursions of the vibrating particles. The "quality" may be very various. Wood, pasteboard, and metal produce each a sound of different quality. The quality of the sound appears to depend partly on the form of the undulations, and partly on the simultaneous existence of undulations of different rapidity. One and the same body, if it possess unequal elasticity in different directions, may, on receiving an impulse, become the seat of undulations of different rapidity in different parts, and will communicate these undulations to a conducting medium, not simultaneously, but at more or less distinct periods, producing thus in the latter a compound wave of peculiar form. This compound wave, or sum of waves, is transmitted to the organ of hearing in the same order and form as it was received by the conducting medium, in which all modulations are propagated with equal rapidity. (*Eisenlohr*, *Lehrbuch d. Physik.* p. 151.) The circumstance, also, that a body may be affected with a transverse and longitudinal vibration at the same time, has a share in the production of the quality of a sound.

If several undulations succeed each other, a more or less prolonged sound results, which may or may not have a musical quality. A succession of similar or dissimilar short sounds, at unequal intervals, gives rise to various unmusical sounds or noises. A succession of short sounds, even at equal intervals, if the individual sounds are distinguishable, does not produce a musical sound. For the production of a sound of musical character, it is necessary that the succession of separate sounds or impulses be not recognisable. The height or pitch of a musical sound depends on the rapidity with which the separate impulses succeed each other. Savart's experiments with the toothed wheel illustrates the mode of production of musical sounds: as long as the separate strokes of the teeth can be heard, the sound has not a musical character; but acquires it when they are made to succeed each other more rapidly, although the unmusical quality of the sounds resulting from the impulse of the separate teeth is still heard. A continued sound of definite musical value may therefore result, not merely from a regular succession of simple waves or vibrations, but also from a regular succession of very compound undulations, such as separately constitute short unmusical sounds. A full and pure musical sound requires for its production simple undulations of sufficient strength without the irregular intermediate undulations. The quality of "tone," or "timbre," possessed by a musical sound, is dependent on the same causes as the quality of a simple sound not musical; the musical sound differs merely in the undulations which produce it, succeeding each other at regular intervals.

III. *Of the undulations by which sound is propagated.*

Of the progressive undulations engaged in the propagation of sound. (After *Weber*, op. cit. p. 501.)—The propagation of the vibrations of sonorous bodies is effected ordinarily by undulations of condensation and rarefaction, not by undulations of inflexion. Sonorous vibrations are propagated even in water by means of undulations of this kind; by a movement, therefore, very different from the undulations of elevation and depression of the surface of the water.

An impulse in every direction imparted to the air at one point gives rise to a spherical wave of condensed air, of the form of a hollow sphere, which extends equally in all its dimensions, maintaining consequently its spherical form. A spherical body suddenly expanding in the air would excite such a wave. The particles of air which receive the impulse from such a body thus suddenly expanding, acquire at first a motion in a direction corresponding to that of the impulse,—namely, in the direction of the radius of the expanding sphere; and, subsequently, when the expanding body contracts again and produces a rarefaction around it, a motion in the opposite direction. All the particles of the air traversed by the spherical wave, or undulation, experience

same movement. The extent of the forward and retrograde motions of the par-
s of air, which is to be regarded as the same thing as the height of the elevation
he undulations on the surface of water, decreases with the progress of the wave,
le the thickness of the wave remains the same, just as a circular wave excited
n the surface of water becomes lower as it extends itself, though its breadth re-
ns unaltered. The cavity of the spherical wave increases uniformly in diameter;
its circumference consequently increases as the square of its diameter. The eleva-
of the undulation decreases in the same ratio. This is the cause why the inten-
of a sound diminishes, in the open air, in an inverse ratio with the squares of the
ance from its origin. In the motion of the air in a tube no cause for the diminution
e intensity of the sound exists.

he intensity with which sounds are conducted depends, *cæteris paribus*, on the
tion existing between the sonorous body and the conducting medium. The more
latter resembles in its physical properties the body which yields the sound, the
e perfectly will it conduct it, and *vice versâ*. The column of air of a wind instru-
t, for example, communicates its sonorous vibrations in such perfection to the
sphere, that the interposition of other media does not tend to increase the in-
ity of the sound; while to solid bodies, on the contrary, the vibrations of a column
ir are not readily communicated. On the other hand, solid bodies impart their
ations imperfectly only to the air, and in all their intensity to other solid bodies.
eover, sonorous undulations, in their transition from one medium to another
rent medium, are, like rays of light, partly reflected. These considerations afford
xplanation of the interruption offered by rocks to sounds excited in the air, and
he circumstance that the sonorous vibrations of a solid body, such as a rod, are
municated to the ear with greater intensity by means of a cord than through the
rvention of the air. Mr. Wheatstone states, (*Ann. de Chimie et de Phys.* t. xxiii.
17,) that by means of a wire the sounds produced by a stringed instrument, may
onducted to a resounding body placed at a considerable distance.

esonance is a means of rendering a sound louder than it is as produced by the
ding body itself. It consists in increasing the extent of surface of a soniferous
ium similar in kind to the sounding body. Hence the increase of sound produced
lacing a vibrating tuning-fork upon a solid body. The influence of the bridge
sounding-board of stringed instruments is due to the same principle. Greater
nance is, however, produced by an insulated body than by one which has no
umscribed surfaces; for an insulated body reflects back a part of the undulations
in it at its borders and surfaces, and, these reflected undulations meeting with the
ulations newly excited in it, an increased extent of the excursions of the oscillating
icles, answering to the increased height of the elevations of flexion-waves, is pro-
ed. (*Weber*, op. cit. p. 536.)

tationary vibrations in bodies conducting sound.—Stationary vibrations are developed
odies to which sonorous vibrations are communicated, and which are insulated,
at the same time elastic. We have stated that progressive sonorous undulations
n insulated body are reflected at its borders and angles; and that, in consequence
his, the undulations newly communicated to the body, and those reflected within
neet and intersect each other.

he sound of one body may, under certain conditions, excite in another insulated
tic body not merely resonance, but also a new production of sound; the sound
tted by the body thus secondarily thrown into sonorous vibration, being in this
the note peculiar to itself; and different from that produced by the body primarily
cted. Stretched strings will reciprocate the sounds of other bodies by the notes for
ch their degree of tension fits them; for this to occur, it appears to be necessary
merely that the sonorous body secondarily affected be very elastic and bounded by
surfaces, but also that the number of the vibrations in the note which it is
pted to yield should bear a simple numerical relation to those of the original
nd.

n musical glasses filled with water, and the vessel thrown into sonorous vibrations
means of a violin-bow, the surface of the water dividing itself into several com-
tments (four, six, or eight, according to the height of the note produced,) separated
nodal lines, between which, if the stroke of the bow was gentle, stationary undu-
ons are seen directed perpendicularly against the internal surface of the vessel. If
stroke of the bow was stronger, other figures are produced; and, by the decus-

cation of undulations having different directions, rhomboidal stationary undulations are developed. The water, moreover, accumulates in the vibrating segments, and is spirted out of the vessel when the action of the bow is violent. If the glass vessel is thrown into vibration by the friction of the finger upon its margin, the vibrating segments and the nodal lines move round in a circle, following the movement of the finger.

The application of the violin bow to the border of a lamina of glass, of which the surface is covered with a thin layer of water, gives rise to the same phenomena in a still more marked degree.

The rapidity with which sound is propagated depends on the density and elasticity of the body. The rapidity in dry air, at a temperature of 32° Fahr. is at the rate of 332.49 metres, or 1022.194 feet (Parisian measure), [or about 1090 feet English measure] in a second. Its rapidity increases with the rise of temperature. Sound is propagated in water with about four times greater velocity than in air; in solid bodies its rapidity of transmission is still greater. Iron propagates sound with ten and a half times, wood with eleven times, greater rapidity than atmospheric air.

Reflection of sound.—In relation to their reflection, the undulations of sound resemble those of light; in passing from one medium into another different one, they are in part reflected, and in part only propagated onwards. The ticking of a watch placed in the focus of a concave mirror may be heard in the focus of another mirror placed so as to receive and concentrate the reflected sonorous undulations. It is owing to sonorous vibrations of air being propagated with more facility in that medium than they are imparted from it to solid bodies, that sounds are transmitted in their full intensity through tubes, just as on the same principle solid rods propagate sonorous vibrations to great distances almost without any loss of intensity. A *speaking-trumpet* represents a parabola, in the focus of which the sound is excited. Being reflected by the parabolic surface, the sonorous undulations are all thrown in a direction parallel to the axis of the parabola. The cause of the increased intensity given to the sound by the *speaking-trumpet* is, for the most part, the coincidence of newly excited undulations with others already reflected, producing undulations with greater condensations and rarefactions. But the resonance of the confined mass of air in the tube also contributes to this effect; for the air of a tube open at both extremities, while it propagates sound, also becomes the seat of resonance. The *ear-trumpet* becomes narrower towards the ear, and consequently concentrates the sonorous undulations. If its walls have the parabolic form, and the focus of the parabola be at a point near the ear, sonorous undulations coming in a direction parallel with the axis of the parabola will of course be brought to a focus near the ear. (*Eisenlohr*, loc. cit. p. 164.) If a reflecting surface is situated so as to throw sonorous undulations upon the ear, and is at such a distance that the reflected undulations reach the ear perceptibly later than the undulations coming direct from the sounding body, an echo results, which is perfect when the difference of time is so great that the two series of undulations strike the ear at perfectly distinct periods.

CHAPTER II.

II. OF THE DIFFERENT FORMS OF THE AUDITORY APPARATUS, AND OF ITS ACOUSTIC PROPERTIES.

1. *Of the different forms of the organ of hearing.*

In the greater number of invertebrate animals there are no parts known which can be regarded as analogous to the organ of hearing of the higher clases; and in the case of many animals it may be doubted whether they really hear at all; for every reaction of nerves under the influence of vibrations cannot be called the sensation of sound, since

sense of touch is capable of perceiving the same vibrations as a
nor.*

1 all cases the first essential of an organ of hearing is the special
re endowed with the property of perceiving impulses as sound; and,
t to this, an apparatus adapted for conducting these impulses to the
re. Inasmuch, however, as all matters have the property of propa-
ng sonorous vibrations as undulations of condensation, it is evident
: a special apparatus for conducting these vibrations may be absent;
this enables us to understand why no special auditory apparatus has
n hitherto found in many invertebrate animals. The auditory nerve,
ierely in contact with the solid parts of the head, will be as certainly
cted by the vibrations communicated to those parts as if it were
ad out in a special organ.

'he simplest form of the organ of hearing in which a special ap-
atus is added to the nerve with the specific endowment, is a small
containing fluid, with the auditory nerve expanded upon it. The
orous vibrations are communicated to this organ, either through the
lium of the hard parts of the head alone, or at the same time by the
tiguous hard parts, and by a membrane lying freely exposed to the
rounding medium. This is the form of the organ of hearing in the
stacea among the Articulata, and in the Cephalopoda among the
llusca.

'he organ of hearing in the vertebrata is in no instance so simple
in these invertebrate animals. It was formerly thought that the
romyzon resembled the Invertebrata in this respect; but my re-
rches have shown that they possess a complicated labyrinth with
semicircular canals. In tracing the organ of hearing from fishes
to Mammalia, we find it present a progressive development and
reasing complexity.

'n birds the organ of hearing has in some respects—namely in the
icture of the tympanum, columella, and cochlea,—the same confor-
tion as in the Crocodilida and Lacertæ. The tympanum communi-
s with cavities in the cranial bones, which thus become filled with
and increase the extent of surface tending by resonance to render
nds more intense.

Mammalia generally have an organ of hearing, which is not essen-
ly different from that of man, and the varieties of form which it
sents are not, for the most part, of such physiological importance as
render it necessary for us to describe them. The cochlea is always
ivoluted, and possesses a spiral lamella, formed partly of bone and
tly of membrane, running round the central modiolus; the cochlea
the Ornithorhynchus, and that of the Echidna, are the only excep-
ns, resembling in all respects the same part in birds. The bony
npanum has in many Mammalia the form of a large osseous pouch,
ierally resulting from a development of the os tympanicum. In many

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For an account of the parts regarded as organs of hearing in insects, see Compa-
i, Obs. Anat. de Aure Interna Comparata; Patavii, 1789: Treviranus, Ann. d.
tterauischen Gesellschaft, B. i. 2; Frankfort, 1809, p. 169: Ramdohr, Magazin d.
ellschaft Naturforschender Freunde; Berlin, 1811, p. 389; J. Müller, Physiol. des
ichts-sinnes, p. 437.

animals the cavity of the tympanum extends into other contiguous bones. In some there is also a second superior tympanum, formed by the pouch-like expansion of the os petrosum upwards and backwards; such a cavity exists, for example, in the genera Pedetes, Dipus, and Macroscelides. These are all means for increasing the extent of the cavities for resonance. The Cetacea and the Ornithorhynchus have no external ear; the Eustachian tube in the Delphinus family opens into the nasal cavity; and the external auditory passage of animals living entirely in the water is extremely narrow.

The ultimate distribution of the auditory nerve in the cochlea, and the observations of Treviranus and Gottsche relative to that subject, have been referred to at page 493. Just as the nervous fibres are spread out in the cochlea upon the lamina spiralis for the purpose of being in contact on both sides with the fluid of the labyrinth, so also in the ampullæ of the semicircular canals they are, as Steifensands has shown, (*Müller's Archiv.* 1835, 171,) expanded upon a process, which however is not carried entirely through the ampulla, but merely projects into it. Into the ampulla of each semicircular canal in Mammalia a transverse rounded body projects like an imperfect septum at the part corresponding to the expansion of the nerve on the ampulla.* In birds, a process with a rounded extremity projects upwards from this septum, and another similar one downwards; so that the whole resembles a cross, of which the transverse branches are fixed to the walls of the ampulla, the perpendicular branches free. In the tortoise, the rounded septum of the posterior ampulla has merely one boss-like prominence (umbo) in its centre. The septum of the anterior ampulla is placed transversely upon the parietes of the cavity, and has not this prominence: in the external ampulla only half of the septum exists. In crocodiles and lizards the external ampulla resembles that of the tortoise; the others have the septum of the cruciate form. In fishes the septum is a rounded transverse fold.

All the acoustic contrivances of the organ of hearing are means for conducting the sound, just as the optical apparatus of the eye are media for conducting the light. Since all matter is capable of propagating sonorous vibrations, the simplest conditions must be sufficient for mere hearing, for all substances surrounding the auditory nerve would communicate sound to it. In the eye a certain construction was required for directing the rays or undulations of light in such a manner that they should fall upon the optic nerve with the same relative disposition as that with which they issued from the object. In the sense of hearing this is not requisite. Sonorous vibrations having the most various direction and the most unequal rate of succession, are transmitted by all media without modification, however manifold their discussations; and, wherever these vibrations or undulations fall upon the organ of hearing and the auditory nerves, they must cause the sensation of corresponding sounds. The whole development of the organ of hearing, therefore, can have for its object merely the rendering more perfect the propagation of the sonorous vibrations and their multiplication by resonance: and, in fact, all the acoustic apparatus of the organ may be shown to have reference to these two principles.

For the mere perception of sounds, therefore, neither membrana tympani, ossicula, cochlea, semicircular canals, nor even the vestibule and fluid of the labyrinth, are essential. Hence all these parts may be absent.

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* Steifensands' figures of this structure in man will be found copied in Mr. Wharton Jones's art. Organ of Hearing, in the Cyclopæd. of Anat. and Physiology, which may be consulted with reference to the structure of the human ear generally.

the propagation of sound to the labyrinth in animals living in the air.

he propagation of the sonorous vibrations from the surface of the y to the fluid of the labyrinth, requires in an animal living in the air uch more complicated apparatus than in an aquatic animal, in con- uence of the transition of the vibrations from air to the solid parts ich surround the organ of hearing and the fluid of the labyrinth g attended with much greater difficulty than the transition of the rations from water to solid bodies. Accordingly, in most animals g in the air, the labyrinth has two fenestræ, of which one is closed a membrane, the other by a solid operculum. Most of these ani- s have also a tympanum and Eustachian tube, and a double means onducting the sound from the exterior to the labyrinth,—namely, a in of solid bodies, the ossicula auditus, interposed between the mem- na tympani and the fenestra ovalis of the labyrinth; and the air of tympanum, which conducts the vibrations from the membrana pani to the membrane of the fenestra rotunda. The dispute which occupied physiological writers, as to which of these is the true con- ting medium of the sound, has no scientific grounds. The air, mbranes and small bones of the ear, are all capable of conducting orous vibrations, and they do respectively what their physical pro- ties adapt them for. The propagation of the sound in two different ys simultaneously must necessarily strengthen its impressions. The s by which the propagation of sound from the exterior to the laby- h of animals living in the air are regulated, have not hitherto been ermined. We shall, therefore, investigate the subject as fully as we e done that of the process of hearing in aquatic animals.

To learn the acoustic value of each part of the apparatus, it is requisite tudy them in the order of their progressive development.

The propagation of sound to the fluid of the labyrinth in animals titute of tympanum is seldom left to the conducting power of the nial bones alone. Sonorous vibrations are imparted too imperfectly m air to solid bodies, for the propagation of sound to the internal ear e adequately effected by that means. In nearly all animals living the air, even in those which have no tympanum, the labyrinth has opening, or fenestra, towards the exterior, which, when the tympa- n is absent, is covered by the skin and muscles.

. *Sonorous undulations, in passing from air directly into water, suffer a siderable diminution of their strength; while, on the contrary, if a tense mbrane exists between the air and the water, the sonorous undulations are municated from the former to the latter medium with very great intensity.* This is the fundamental fact from which we start. We have in this t at once an explanation of the use of the fenestra rotunda, and of the mbrane closing it. They are the means of communicating in full ensity the vibrations of the air to the fluid of the labyrinth, whether tympanum exist or not. This peculiar property of membranes is result, not of their tenuity alone, as will be readily conceived, but of elasticity and capability of displacement of their particles. In sing from the air into a solid body, sonorous vibrations are at once dered feeble, whether the solid body itself be thick or thin; for the impediment to the propagation of the vibrations exists at their very transition from the one medium to the other. A membrane cannot therefore, with respect to its influence in communicating sound from air to water, be regarded merely in the light of a very thin body. It is owing to the extensile property of membrane that sonorous undulations are so readily communicated to it from air, as though it were itself air; and that it so readily imparts them again to water, as though it were water.

It is, moreover, not necessary that the membrane be impregnated with moisture; the membrane covering the end of the pipe may be dry, and yet the sound transmitted by it, before it has become softened by the water, will be loud. This fact finds its application in the membrane of the fenestra rotunda in animals provided with a tympanum.

II. *The sonorous vibrations are also communicated without any perceptible loss of intensity from the air to the water, when to the membrane forming the medium of communication there is attached a short solid body, which occupies the greater part of its surface, and is alone in contact with the water.*—This fact elucidates the action of the fenestra ovalis, and of the movable plate of the stapes which occupies it in animals living in the air, but destitute of tympanum and membrana tympani.

Observations prove that both fenestræ—that closed by membrane only, and the other with which the movable stapes is connected—transmit very freely the sonorous vibrations from the air to the fluid of the labyrinth.

Progagation of sound by the membrana tympani and ossicula auditus.

III. *A small solid body, fixed in an opening by means of a border of membrane, so as to be movable, communicates sonorous vibrations, from air on one side, to water, or the fluid of the labyrinth, on the other side, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect if the solid conductor thus occupying the opening (fenestra of the labyrinth) is by its other end fixed to the middle of a tense membrane which has atmospheric air on both sides.*

Vibrations of the air are communicated to solid bodies with difficulty, and with a considerable diminution of their intensity; but a membrane is readily thrown into motion by them. Savart has shown that membranes of small extent, as the membrana tympani itself, even when made tense, are so affected by sonorous vibrations excited in their vicinity as to cast off sand which is strewed over their surface. It may also be proved by direct experiment, that a tense membrane is a much better conductor of the undulations of air than any other solid bodies bounded by definite surfaces; and, what is equally essential, that the vibrations are also communicated very readily by a tense membrane to solid bodies in contact with them. The membrana tympani has not hitherto been considered under this point of view, namely, as the means of transmitting sound from the air to the chain of auditory bones.

The ossicula of the ear are the better conductors of the sonorous vibrations communicated to them, on account of being isolated by an atmosphere of air, and not continuous with the bones of the cranium; for every solid body thus isolated by a different medium propagates vibrations with more intensity through its own substance than it communicates them to the surrounding medium, which thus prevents a dispersion of the sound; just as the vibrations of the air in the tubes used for conducting the

s from one apartment to another are prevented from being dispersed by the solid
s of the tube. The vibrations of the membrana tympani are transmitted, there-
, by the chain of ossicula to the fenestra ovalis and fluid of the labyrinth, their
ersion in the tympanum being prevented by the difficulty of the transition of vibra-
s from solid to gaseous bodies. The membrana tympani being a tense solid body
ided by free surfaces, the sonorous undulations will be partially reflected at its
ces, so as to cause a meeting of undulations from opposite directions within it; it
therefore, by resonance, increase the intensity of the vibrations communicated to
nd the undulations thus rendered more intense will act in their turn upon the chain
ditory bones.

e have now to investigate the nature of the vibrations of the membrana tympani.
they undulations of inflexion, like the transverse vibrations of strings and mem-
es? or are they undulations of condensation? An impulse communicated to a
g or rod in the direction of its length gives rise merely to progressive waves of
ensation, not to vibrations of the string or rod from side to side. But if a suffi-
ly thin body, as a string or membrane, receives an impulse in a direction perpen-
lar to its length or to its surface, undulations of inflexion are also produced. Ac-
tely speaking, the membrana tympani will become the seat of transverse oscillations
never the space through which its particles move in the undulations excited by
rous vibrations of the air exceeds the thickness of the whole membrane; and,
n the impulses of the air have a certain degree of intensity, this must occur. The
ulation and relative position of the small bones of the ear being such as to allow
pproximation of the two extremities of the chain which they form, the oscillations
e membrana tympani are not impeded by them. Even where only one of the
ula exists, as in birds and reptiles, its outer extremity, which is connected with
nembrana tympani, is mobile. We may from these considerations infer that the
ulation of the small bones of the ear has not a relation merely to the action of
les upon them,—which, indeed, is sufficiently proved by reference to comparative
omy, for they have movable articulations in the frog as in man, though they have
no muscles attached to them.

n examining, however, more closely the conditions of the propagation of sonorous
lations in the atmosphere, we find that only the most intense sounds can possibly
rise to oscillations of the membrana tympani as a whole.

calculating the effect of sonorous undulations on the membrana tympani, we
t take into account the difference in the velocity with which sound is propagated
and by the air, and also the resistance offered by its attachments, which, even
gh the extent of the oscillation of the particles of air striking it exceeded the
tness of membrane, would cause the extent of its movement to be much less con-
rable.

he necessity for the presence of air on the inner side of the membrana tympani,—
her words, the necessity for the existence of the tympanic cavity,—to enable the
brana tympani and ossicula auditus to fulfil the objects which we have described,
vious. Without this provision, neither would the vibrations of the membrane be
nor the chain of bones isolated, so as to propagate the sonorous undulations with
entration of their intensity. But while the oscillations of the membrana tympani
eadily communicated to the air in the cavity of the tympanum, those of the solid
ula will not be conducted away by the air, but will be propagated to the labyrinth
out being dispersed in the tympanum. Equally necessary is the communication
he air in the tympanum with the external air through the medium of the Eusta-
n tube for the maintenance of the equilibrium of pressure and temperature between
n.

The propagation of sound through the ossicula of the tympanum to
labyrinth must be effected by undulations of condensation and rare-
ion of their particles only, not by oscillations of the entire bones,
n in cases where the entire membrana tympani oscillates; for, if the
es were in its vibrations alternately more nearly approximated and
oved from the labyrinth, the fluid of the latter cavity must necessa-
be very compressible. The extent through which the individual
ticles affected by the undulations oscillate equals very minute frac-
s only of the length of the stapes.

The long process of the malleus, receives the undulations of the membrana tympani and of the air in a direction nearly perpendicular to itself. The undulations maintain this direction through the whole chain of ossicula quite independently of its direction, and of that of the individual bones forming it. From the long process of the malleus the undulations are propagated to its head, which projects from it at an angle; thence into the incus the long process of which has a direction parallel with the long process of the malleus. From the long process of the incus the undulations are communicated to the stapes, which is united to it at right angles. All these changes in the direction of the chain of bones have no influence on that of the impulse, which remains the same as it was in the meatus externus and long process of the malleus, so that the undulations are communicated by the stapes to the fenestra ovalis in a perpendicular direction.

Tension of the membrana tympani.

IV. *A membrane of small extent propagates sound better in the lax condition than when made very tense.*

The inquiry respecting the capability of the membrana tympani to conduct sound better in its lax or in its tense condition, may be made to embrace membranes generally. We must, however, distinguish here between reciprocation of sonorous vibrations, resonance, and conducting power. The reciprocation of sounds is a phenomenon which bodies rendered elastic by tension are not capable of manifesting in their lax condition.

The result was in all my experiments the same. The sound was transmitted with much greater intensity through the lax membrane than through the membrane made tense by raising the outer extremity of the rod. A watch may be used as the source of the sound in these experiments. But every noise is heard louder when the membrane is lax; and its intensity diminishes in proportion as the tension of the membrane is increased.

The membrana tympani in one's own person may, however, be rendered tense so as to produce this influence on the insensity of sounds at will. 'In the dead subject, the membrana tympani may be rendered more tense in two ways besides by the retraction of the malleus; namely, by exhausting the air in the tympanum by sucking through the Eustachian tube, and by forcing more air into the tympanum through the same canal. In the first case, the membrana tympani is pressed inwards. In the second case, it is forced outwards; the long process of the malleus, however, not being displaced by the pressure of the air within the tympanum, the centre of the membrane is prevented from changing its position, while the rest of it is protruded.

But these modes of tension of the membrana tympani may be practised in the living body also, and in the experiment on our own persons, namely, by a strong and continued effort of expiration while the mouth and nostrils are closed, or by a strong and long-continued effort of inspiration under the same circumstances. In the first case, the compressed air is forced with a whizzing sound in the tympanum, and immediately hearing becomes indistinct. The same temporary imper-

m of hearing is produced by rendering the membrana tympani
, and convex towards the interior, by the effort of inspiration; a
first noticed by Dr. Wollaston. (*Philos. Transact.* 1820.) The
rfection of hearing, produced by the last-mentioned method, con-
s even after the mouth is opened, in consequence of the previous
t at inspiration having induced collapse of the walls of the Eusta-
tubes, which prevents the restoration of equilibrium of pressure
een the air within the tympanum and that without; hence we have
pportunity of observing that even our own voice is heard with
ntensity when the tension of the membrana tympani is great.

the pressure of the external air or atmosphere be very great, while,
count of collapse of the walls of the Eustachian tubes, the air in
nterior of the tympanum fails to exert an equal counter-pressure,
nembrana tympani will of course be forced inwards, and imperfect
ess be produced. It is thus, in my opinion, that we must explain
ingular observation of M. Colladon, that in the diving-bell both the
s of his companions and his own voice sounded faintly. The fact
ot be owing, as has been supposed by some writers, to the bad
ucting power of the condensed air, since air conducts sound better
oportion to its density.

e effect of the increased tension of the membrana tympani is not
nder both grave and acute sounds equally fainter than before. On
ontrary, it was observed by Dr. Wollaston, that, when he had
red his membrana tympani tense by exhausting the cavity of the
anum, he was deaf to grave sounds only. By striking the table
the ends of his finger, he produced a deep dull note; striking it
his nail, he gave rise to a sharp sound. When he had exhausted
mpanum by the effort of inspiration, he could hear the latter sound
the former deeper note was inaudible.

ese facts admit of a practical application in pathology. It is not
rare to meet with persons who are deaf to the more grave sounds
while they still hear distinctly acute sounds, even though they be
ud. One of my colleagues, who is deaf, hears acute better than
sounds. In such cases it is very probable that the membrana
ani is in a state of too great tension. In the present state of obscu-
f the diagnosis of diseases of the ear, this hint may be of some use.

unnatural tension of the membrana tympani may, of course, be
ced by several different causes. It may arise from occlusion of the
achian tube; in which case the air in the tympanum may either be
nded by the heat of the body, and so force outwards the membrana
ani, or it may be partially absorbed, when the membrane would
essed inwards by the air without. Another cause may be a con-
d state of the tensor tympani muscle. In my colleague the
chian tube is free, for he can force air into the tympanum.
n the Eustachian tube is closed, and the tension of the membrana
ani is the consequence of the expansion or partial absorption of
ir in the cavity of the tympanum, the operation of puncturing the
brane, or the mastoid process, may be easily conceived to be bene-
but when the too great tension of the membrana tympani, and
quent deafness, are owing to a contracted state of the tensor tym-

pani muscle, the operation must be useless. This may in part account for the various results obtained from it.

The influence of the musculus tensor tympani in modifying hearing may now be estimated.

If we admit, as a very probable supposition, that the tensor tympani may through reflex nervous action be excited to contraction by a very loud sound, just as the iris and orbicularis palpebrarum muscle are by a very intense light, the impression being conveyed by the sensitive nerve to the brain, and thence reflected upon the motor fibres; then it is manifest that a very intense sound would, by exciting a reflex action of this muscle, induce a deadening or muffling of the ears. A loud sound excites by reflection nervous action, winking of the eyelids, and, in persons of irritable nervous system, a sudden contraction of many muscles. The above supposition has, therefore, great probability in its favour.* Increased tension of the membrana tympani by the tensor tympani muscle, by whatever cause excited, must moreover cause the graver sounds, rather than the more acute, to be heard faintly.

We have now to inquire whether the tensor tympani is subject to voluntary influence. Like the stapedius, it presents under the microscope, according to my observations, the characters common to all muscles of animal life; its primitive fasciculi are regularly marked with the cross striæ.

The opinion that the tensor tympani muscle is subject to the influence of the will was held by Fabricius ab Aquapendente, who maintained that he had himself voluntary power over it, he being able to produce a peculiar noise in his ears at will. Fabricius could perform the movement only on both sides simultaneously. Mayer was acquainted with a gentleman who had such power over the motions of the small bones of his ear that another person could distinctly hear the sound thus produced when their ears were applied to each other.† I have the same power of producing at will a sound in either ear, more particularly in the left, in which I can excite it without causing it on the other side. The sound is of a snapping character, like that emitted by the electric spark, or that produced when the end of the finger, rendered adhesive, is pressed upon paper and then suddenly removed. The cause of this sound appears to me to be a voluntary contraction of the tensor tympani muscle.

An involuntary contraction of the tensor tympani muscle, like its action under the influence of the will, must produce a sound. Many persons will have observed noises in their ear from this cause.

The influence of the stapedius muscle in hearing is unknown. It acts upon the stapes in such a manner as to make it rest obliquely in the fenestra ovalis, depressing that side of it on which it acts, and elevating the other side to the same extent. The only effect which, it appears to me, could be ascribed to it, would be to render tense the membrane by which the base of the stapes is connected with the margin of the fenestra.

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* A very loud noise, such as that of a cannon, if near, may, by forcing in the membrana tympani, give rise to the production of a new sound by that membrane itself; at least, I think, I have observed this in my own person. At the time of the report of a cannon I perceived a cracking or jerking sound, similar to that which is heard when the movement of inspiration is suddenly performed while both the nostrils and mouth are closed, so as to draw inwards, and thus render tense, the membrana tympani.

† Compare Lincke, Handbuch der Ohrenheilkunde; Leipz. 1837; 1, p. 478.

The fenestræ, ovalis and rotunda.

ie existence of two fenestræ for the transmission of sound to the ·inth is not a necessary condition for hearing in animals living in ir which are furnished with a tympanum; for, both a tense mem- e, (such as the membrana tympani secondaria, or membrane of the tra rotunda,) and a movable solid body connected with a tense brane, are capable of conducting sound with considerable intensity ater. Comparative anatomy also furnishes proofs of the truth of tatement; for frogs in which a tympanic cavity otherwise perfect s, have no second fenestra, or fenestra rotunda, the chain of audi- ossicula being in them the only means of conducting the sound to abyrinth. In this case the air in the tympanum can scarcely be ded as an auxiliary, since its sonorous vibrations cannot be com- icated in any intensity to the solid parts of the organ. Its principal nust here be to insulate the small bones of the ear and the mem- a tympani.

ıen both fenestræ exist together with a tympanum, the sound is transmitted to iid of the internal ear in two ways,—namely, by solid bodies and by membrane; th of which conducting media sonorous vibrations are, as my experiments have ı, communicated to water with considerable intensity. The sound being con- l to the labyrinth by two paths will, of course, produce so much the stronger ssion; for undulations will be thus excited in the fluid of the labyrinth from two nt though contiguous points, and by the crossing of these undulations stationary of increased intensity will be produced in the fluid.

s natural to inquire here by which of the paths above indicated the sounds are cted with most intensity from the membrana tympani to the labyrinth; whether gh the chain of bones and the fenestra ovalis, or through the air of the tympanum ie membrane of the fenestra rotunda.

e may express the problem to be decided in other words, thus: vhich succession of media is the intensity of sonorous undulations diminished?—by air, a tense membrane, an insulated and mova- olid body, and water; or by air, a tense membrane, air, another membrane, and then watery fluid? The experiments which I instituted prove very clearly that

Vibrations are transmitted with very much greater intensity to water a tense membrane, a chain of insulated solid bodies capable of free ment, are successively the conducting media, than when the media of nunication between the vibrating air and the water are the same tense brane, air, and then a second membrane; or, to apply this fact to the n of hearing, that *the same vibrations of the air act upon the fluid of byrinth with much greater intensity through the medium of the chain ditory bones and the fenestra ovalis, than through the medium of the f the tympanum and the membrane closing the fenestra rotunda.*

mitated the structure of the tympanum and reached the above result irect experiment.

ıe undulations transmitted by the fenestra ovalis act primarily upon vestibule and the semicircular canals; those transmitted by the fe- a rotunda, upon the cochlea: but those communicated immediately e fluid of the vestibule, inasmuch as they extend as circular waves e fluid, must ultimately reach the cochlea; and the relation of the stra rotunda to the cochlea is by no means constant, since in chelonian reptiles (tortoises and turtles) both fenestræ exist, though there is no proper cochlea.

The Eustachian tube.

The Eustachian tube is never absent when the tympanum exists. Its great importance in rendering hearing perfect is proved by the circumstance of its occlusion as a consequence of disease, being always attended with deafness and tinnitus. But it cannot, from these cases of disease, be determined whether the Eustachian tube is itself essential to the hearing of sounds with distinctness and intensity, or whether its occlusion affects hearing only indirectly.

It may be easily conceived that the ill effect of obstruction of this passage would be equally great whether its office were merely to prevent the production of too great tension of the membrana tympani by expansion or condensation of the air in the tympanum, or to carry off the mucus generated in that cavity by the ciliary motion of its mucous lining. All the provisions by which the tympanum has been adapted to the better propagation of sound would be rendered unavailing if it were to become filled with mucus.

The different offices which might be, and have been, attributed to the Eustachian tube are various.

The principal object for the fulfilment of which this tube exists, wherever there is a tympanum, appears to me to be the maintenance of the equilibrium between the air within the tympanum and the external air, so as to prevent inordinate tension of the membrana tympani, which would be produced by too great or too little pressure on either side, and the effect of which would be imperfection of hearing. It is not the increased or diminished density of the air on either side of the membrane which is of the chief importance, but the tension of the membrana tympani which they necessarily produce, and which always interferes with the integrity of hearing.

It is on this principle that we must explain the good effect of catheterising the Eustachian tube, or of perforating the membrana tympani, or mastoid process of the temporal bone, in many cases of deafness caused by chronic occlusion of the tube. While, however, I maintain that this is the principal office of the Eustachian canal, I do not deny that it has other uses, of which the next in importance appear to me to be the modification of the sound so as to render it more clear, the supplying the tympanum with air, and the discharge of the secretion of that cavity.

When the Eustachian tubes are sufficiently wide, the density of the air within the tympanum will be kept constantly equal to that of the external air; and, when the latter rapidly increases in density, the air within the tympanum will immediately acquire the same density, so as to balance the increased external pressure upon the membrana tympani, without our being conscious of any change. In proof, however, that in other cases the balance of the pressure within the tympanum and upon its exterior may be disturbed, the observations of persons who have descended in the diving-bell may be adduced.* Carus, (*Bericht über die*

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* See also Dr. Todd's observations in the Cyclopædia of Anat. and Physiol. art. Hearing, p. 575.

ammlung der Naturforscher in Jena,) also, in ascending high itains, perceived a sensation of tension in the ears; and, after a in height was attained, a snapping sound, which was repeated at tions differing about six hundred feet from each other. Whether sensations be perceived or not by others, will, of course, depend irt on differences of individual conformation. I do not myself ect to have experienced anything of the kind. Before, however, tate of disturbed balance of pressure had reached its maximum, uld remove it by a voluntary action of the tensor tympani, which o attended in me with a snapping sound.

The external auditory passage.

e meatus auditorius externus influences the propagation of sound tympanum in three ways: 1, inasmuch as the sonorous undula- entering directly from the atmosphere are transmitted by the air tube immediately to the membrana tympani, and are prevented being dispersed; 2, by the walls of the passage conducting the ous undulations imparted to the external ear itself by the shortest to the place of attachment of the membrana tympani, and so to this brane; 3, by the resonance of the column of air contained within assage.

a conductor of undulations of air, it receives the direct undulations of the atmo- , of which those which enter in the direction of the axis of the canal must e the strongest impression. The undulations which enter the passage obliquely e reflected by its parietes, and will thus by reflexion reach the membrana tym- By reflexion, also, the external meatus receives the undulations which impinge the concha of the external ear, when their angle of inflexion is such that they rown towards the tragus. Other sonorous undulations again, which could enter eatus from the external air neither directly nor by reflexion, may still be brought by "inflexion;" undulations, for instance, whose direction is that of the long f the head, and which pass over the surface of the ear, must, in accordance with ws of "inflexion," be bent into the external meatus by its margins. The action se undulations will, however, be most intense which enter the meatus directly, r by reflexion nor inflexion. Hence we are enabled to judge of the point whence comes, by turning one ear in different directions.

have next to consider the walls of the meatus as solid conductors of sound; for vibrations which are communicated to the cartilage of the external ear, and not ed from it, are propagated by the shortest path through the parietes of the audi- assage to the membrana tympani. Hence both ears being close stopped, the of a pipe is heard more distinctly when its lower extremity covered with a mem- is applied to the cartilage of the external ear itself, than when it is placed in t with the surface of the head.

tly, the external auditory tube is important, inasmuch as the air which it con- like all insulated masses of air, increases the intensity of sounds by resonance. nvince ourselves of its really having this influence, we need merely lengthen the ge by affixing to it another tube. Every sound that is heard, even the sound of n voice, is then much increased in intensity. If tubes of considerable length ed, and their length is adapted to the sound, the column of air in them will re- ate it by their own fundamental notes, as the MM. Weber have shown. Shorter ns of air do not thus reciprocate sounds, but merely increase their intensity by nce.*

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he resonant action of the meatus, particularly when lightly closed, was pointed out by heatstone, in the Journal of Science and Arts for 1827, vol. ii. New Series.

Cartilage of the external ear.

The action of the external ear upon sonorous vibrations is partly to reflect them, and partly to condense and conduct them to the parietes of the meatus externus. With respect to its reflecting action, the excavation called the concha is the most important part, since it directs the reflected undulations towards the tragus, whence they are thrown into the auditory passage. The other inequalities of the external ear do not promote hearing by reflexion, (see *Esser, in Kastner's Archiv.* xii.;) and, if the conducting power of the cartilage of the ear were left out of consideration, they might be regarded as destined for no particular use; but, receiving the impulses of the air, the cartilage of the external ear, while it reflects a part of them, propagates within itself and condenses the rest, as all other solid and elastic bodies would do. This action of the cartilages of the external ear is with justice insisted on by M. Savart. The sonorous vibrations which it receives by an extended surface are conducted by it to its place of attachment.

Regarding the cartilage of the external ear as a conductor of sonorous vibrations, all its inequalities, elevations and depressions, which are useless with relation to reflexion, become of evident importance; for those elevations and depressions upon which the undulations fall perpendicularly, will be effected by them in the most intense degree; and, in consequence of the various form and position of these inequalities, sonorous undulations, in whatever direction they may come, must fall perpendicularly upon the tangent of some one of them. This affords an explanation of the extraordinary form given to this part.

The external ear of many animals is in every respect comparable to an ear-trumpet capable of being directed different ways at will, in which the undulations of the air are propagated onwards and concentrated at the same time, and whose parietes also are capable of transmitting the sonorous vibrations communicated to them. Moreover, this form of ear, like the ear-trumpet, lengthens the column of air of the auditory passage, and increases the influence which its resonance has in rendering the sound more intense.*

Solid bodies and masses of air in the neighbourhood of the labyrinth influencing sounds by their resonance.

In this light we must regard, not merely the cranial bones, but all cartilages and membranes in the vicinity of the organ of hearing.

By the resonance of bodies of air occupying cavities within the head our voice is rendered more audible, not merely to others, but also to ourselves. Any mass of air bounded by a different medium is excited to resonance by a sound produced near it. The circumstance of persons whose hearing is bad holding their mouth open while listening, appears to have some connection with the resonant power of the air in the mouth: it cannot have reference to the transmission of the sound through the Eustachian tubes, since a tuning-fork vibrating even at the back of the mouth is heard but faintly. The habit of holding the mouth open in persons whose hearing is imperfect, may, however, have for its object more particularly to dilate the cartilaginous portion of the auditory passage, which, as Elliot remarks, is effected by opening the mouth.

At all events, the intensity which the voice of another person acquires when he speaks through a tube placed in front of our mouth or nostrils,

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* The great influence of the insulated column of air in increasing the intensity of the sounds is frequently overlooked in the case both of the ear-trumpet and of the speaking-trumpet.

: depend in part on the resonance of the cavities containing air ıh lie in our head.

ren the air in the external auditory passage and in the tympanum ın action of resonance. This is perceived when we simply elongate ıuditory passage by inserting a tube into it. We then hear not ıly the sound of the circulation in the ear, and of the slight movets of the air apparently at rest, which, without being necessarily rous undulations, produce a sound in the tube, just as a sound is uced in a musical pipe by a blast of wind; but every sound, as that of our own voice as of external bodies, is accompanied by a ıct resonance.

propagation of sound to the labyrinth through the cranial bones compared with that through the tympanum.

r the apparatus of the tympanum sonorous vibrations are comicated to the labyrinth on its external side, through the medium ıe fenestræ, whence they spread in all directions through the periıh or aqua Cotunnii.

ır sounds to be heard through the medium of the cranial bones ə, it would be necessary for the apparatus of the tympanum to be nt, as well as the external meatus closed. It is probable that ds propagated by the air would then either be inaudible, or be d with excessive faintness, while the sonorous vibrations of solid es conducted by solid media to the head would still be audible if labyrinth were free from lesion. This test might be employed in ı of deafness, to ascertain whether the labyrinth and auditory nerve ıound.

deaf person, who is unable to hear any sound through the medium e atmosphere, is nevertheless sometimes able to perceive the sound rong blows upon the ground or floor, owing to the vibrations being ucted to his ear through the solid parts of his body. There is a difficulty, however, in distinguishing between the perception of ıtions by the sense of touch and by the sense of hearing. All grave ds act readily upon the nerves of touch; the sonorous vibrations elt distinctly as tremors when the hand is applied to the thorax e speaking, or when a solid body emitting a sound is held in the l. The sonorous vibrations excited in water by means of a musical are not sensible to the touch when the hand is dipped in the water, ıre perceived distinctly if a solid body held in the hand is partially ersed in it. This perception of sonorous vibrations by the sense of h has given rise to the false notion that other nerves than the audinerve are capable of the sensation of sound.

Of the propagation of sound to the ear by different media.

By the air.—Sounds are most frequently heard through the meı of undulations of the air, whether these are primarily excited in : imparted to it by other bodies. Sonorous undulations are comicated to the ear with much greater intensity if originally produced ıe air, and not merely conducted by it from other bodies; for, in the ıition of sonorous vibrations from other media into air, they suffer ninution of their force.

The obstruction to the sound is still greater when it has to pass first from air into water, and then again from the water into air, before reaching the organ of hearing; hence persons in the diving-bell hear nothing of sounds generated in the atmosphere above. (See *Gehler's Physic. Wörterb.* viii. p. 449.)

The loudness of sounds heard through the medium of the air is, moreover, influenced by its density and degree of dryness. The velocity of sound increases with the diminution of the density of the air, but its intensity decreases.

2. Direct propagation of sound to the ear (that is, to the membrana tympani) by water, may be observed in bathing. All sounds generated in the water itself are then heard very distinctly. This fact, which was proved by the experiments of Nollet and Monro, is known to every bather. Sounds produced in the air, and merely transmitted from it to the ear by the water, are, on the contrary, not heard well, on account of the considerable diminution of intensity which sonorous undulations undergo in their transition from air to water.

3. Direct propagation of sound to the organ of hearing by solid bodies.—Sonorous undulations, excited primarily in the air, are conducted to the tympanum best by that medium; and, in the same manner, solid bodies form the best conducting medium for sounds emitted by solid bodies. The sound produced by striking a piece of wood or metal is feeble when communicated to the ear by the atmosphere only; while it is very intense if a cord attached to the sounding body is held between the teeth, or brought into contact with both ears peviously plugged. Thus Herhold and Rafn were enabled to conduct the sonorous vibrations produced by striking a spoon so perfectly, by means of a cord fixed to it, that at the distance of three hundred yards it still sounded like a bell. The use of the ear-trumpet consists partly in the undulations of the air being conducted to the ear with undiminished intensity, and partly upon the resonance of the column of air contained in the trumpet; but its effect is also increased by the vibrations of the resounding walls of the tube being communicated immediately to the solid parietes of the meatus auditorius. Of this we may easily convince ourselves by holding the ear-trumpet by the side between our teeth while our ears are stopped, and then causing another person to speak into the mouth of the tube: the condensation of the undulations of the air in the tube can here have no influence; and, nevertheless, an extremely loud sound is heard, which is due to the resonance of the tube itself, but which, if conducted to the ear by the atmosphere only, would be scarcely heard.

The immediate propagation of sound by solid parts to the organ of hearing comes into play also when the ear is applied to the surface of the ground for the purpose of listening. The sounds are heard still better if the ear is stopped, and the plug touches the ground.

The *stethoscope* again affords us an example of the propagation of sounds from solids, through other solid bodies, to the solid parts surrounding the organ of hearing. The use of the stethoscope has but little advantage over the application of the bare ear, except so far as the sound is increased in intensity by the resonance of the tube. With

dinary construction, the stethoscope conducts sounds to the ear in
vays,—namely, by its solid portion, which receives the sonorous
lations from the solid body yielding the sound, and transmits them
solid parts of the head around the organ of hearing; and by the
nn of air in its interior, which receives the sound also from the
body, but transmits them through the air of the meatus externus
membrana tympani. The interior column of air is a much less
ive conducting medium than the wooden tube around, on account
e difficulty attending the transition of sonorous vibrations from
to air, but it is of use by its resonance. Hence a simple solid rod
not answer the purpose of a stethoscope. Sounds may be heard,
ver, very distinctly by means of a mere rod, if the ear be stopped
plug of chewed paper, and the one end of the rod be applied, not
e plug itself, on account of the sound of friction which would be
iced, but to the external ear near it. Here the sonorous undula-
are communicated more completely to the walls of the external
us by means of the plug, and are thence propagated to the mem-
tympani.

cases of deafness, where the undulations of the air do not make
ient impression even with the aid of an ear-trumpet, it is some-
of use to convert the undulations of the air into undulations of
bodies, and conduct these to the organ of hearing by solid media.
is best effected, when the object is to hear the voice of another
n, by causing him to direct his voice into a basin, whence it is
ucted to the ear by a rod held between the teeth, or applied to a
inserted into the meatus auditorius of the deaf person.*

3. *Acoustic properties of the labyrinth.*

e *fluid of the labyrinth, aquula Cotunnii, or perilymph,* first claims
ttention as the most general and constant of the acoustic provisions
e labyrinth. In all forms of organs of hearing, the sonorous vibra-
affect the auditory nerve through the medium of a fluid. On this
int, the vibration of the particles in the nerve itself will probably
uch more uniform in character than if merely the surfaces of the
had been in contact with solid parts; in which case, the more in-
l particles of the nerve, being distant from the surface of the solid
, would be acted on in a different manner from the more superficial
cles. Muncke (*Gehler's Physik. Wörterb.* iv. 2, p. 1211,) remarks,
reference to the fluid of the labyrinth, that water, although ill-
ted for the generation of sound, is nevertheless an excellent con-
or of it, even a better one than air. This I cannot admit; it can
ue only with respect to the velocity of the propagation of sound;
undulations of air are conducted with least loss of intensity by air,
of water by water.

e passages called aqueducts appear to me to merit no consideration
lation to the physiology of hearing. They contain neither mem-
ous canals nor fluid, nor even venous trunks, but merely serve to
the periosteum of the cranial bones and dura mater into connection

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the experiments of this kind on the hearing of deaf persons by means of solid conduc-
collected in the works of Chladni, (Akustik, p. 262, 286,) and Lincke (op. cit. p. 530.)

with the internal periosteum of the labyrinth. (*Müller's Archiv.* 1834, p. 22.)

There are three grades of development of the labyrinth: 1, a mere vestibule with a sacculus; 2, a vestibule with semicircular canals, and a membranous labyrinth of correspondent form; 3, the preceding parts with the cochlea.

Vestibule, semicircular canals.—The function usually ascribed to the semicircular canals is that which Scarpa attributed to them; namely, the collecting of the sonorous undulations from the bones of the cranium. Canals generally influence sound by the resonance of their contents, by the condensed propagation of the sonorous undulations in their interior, and by the resonance of their walls.

No influence can be attributed to the canals of the labyrinth as resulting from the resonance of their contents; for water bounded by solid bodies is capable of perhaps no perceptible resonance, its undulations not being reflected by its surfaces when thus bounded. Water seems to be little adapted, also, for collecting sonorous undulations from surrounding solid bodies.

It may therefore be inferred, that though the semicircular canals have probably in some degree the power of conducting sounds in the direction of their curve, yet this conducting power is in them much less perfect than in tubes containing air. Some slight increase of intensity of the impression on the nerve of hearing, will result from the circumstance that the same undulation which enters one extremity of a semicircular canal from the vestibule will return with a part of its force by the other extremity. Dr. Young has ascribed some importance to this circumstance.

This degree of reinforcement of the impression of hearing by means of the semicircular canals, will take place even when the impulse is communicated to the labyrinth, not through the fenestræ, but by the cranial bones, as in fishes, and partly in man.

The resonance of the bony walls of the semicircular canals, excited by sonorous undulations in their fluid contents, comes next under consideration. It is found that when sonorous vibrations are imparted to solid surfaces in contact with water, the sound is, *cæteris paribus*, always heard with greater intensity near these surfaces than in other parts of the fluid; in an experiment to verify this fact, the conducting-rod of course must not actually touch the solid surface. If two such resounding surfaces are situated very near to each other, the sonorous undulations of the water between them have necessarily greater intensity.

If, then, we admit that the membranous semicircular canals have the conditions requisite for collecting the sonorous undulations of the cranial bones in their fluid contents, and for conducting them through their curved cavity more readily than they are carried off by the surrounding hard parts in the original direction of the undulations or impulses, the increased intensity of the sonorous vibrations thus attained will be of advantage in acting on the auditory nerve where it is expanded in the ampullæ of the canals, and in the sinus communis. Where the membranous canals are in contact with the solid parietes of the tubes, this action must be much more intense. But the membranous semicircular canals must have a function independent of the surrounding hard parts; for in the Petromyzon they are not separately enclosed in solid substance,

e in one common cavity with the sinus communis,—a fact of great physiological
tance.*
tenrieth and Kerner imagined that the different canals had the power of making
quainted with the direction whence sound comes. But we do not appear to have
erception of the direction of sound, except as far as we can judge from its acting
strongly on one ear than on the other, or from the difference in its intensity
ding as the direction of the external ear and concha is varied. Even supposing
ere able to distinguish the direction of the impulse of the vibrating particles
upon our auditory nerve, this direction would always be twofold; for, after
the impulse, the particles vibrate in the opposite direction, and this alternation
vement is regularly repeated in the production of a musical sound.
e *otolites* or *calcareous lapilli*† found in the labyrinth of fishes and fish-like Am-
, and the *crystalline pulverulent masses* which supply their place in other animals,
l necessarily reinforce the sonorous vibrations by their resonance, even if they
t actually touch the membranes upon which the nerves are expanded; but, inas-
as these bodies lie in contact with the membranous parts of the labyrinth, they
unicate to these membranes and the nerves vibratory impulses of greater inten-
han the aqula Cotunnii can impart. Sonorous undulations in water are not
ived by the hand itself immersed in the water, but are felt distinctly through the
m of a rod held in the hand.
is appears to me to be the real office of the lapilli and crystalline pulpy masses
e labyrinth. The opinion that the crystalline particles of these masses are,
g the action of sonorous undulations on the ear, thrown off from the internal
e of the membranous labyrinth in the same way that dust or sand is thrown into
n upon vibrating solid laminæ and membranes, is not confirmed by experiment;
e dust floating on water does not present the slightest appearance of movement
g the passage of sonorous undulations.

he cochlea.—In investigating the acoustic properties of the labyrinth,
comes necessary that we should inquire the direction in which
lses and undulations are propagated in the solid parts and fluid of
pparatus.

y summing up the experiments in this head, we should say that
piral lamina of the cochlea must be regarded as a surface upon
h all the fibres of the cochlear nerve are spread out, so as to be
ly simultaneously exposed to the impulse of the sonorous undula-
and simultaneously thrown into the maximum state of condensa-
and again into the maximum state of rarefaction. According to
view of the use of the cochlea, it would make no essential differ-
if the nervous fibres were spread out upon several distinct circular
s surrounding the modiolus, instead of a continuous spirally wound
na; but the latter form employed by nature has this advantage,
all parts of the spiral lamina are so connected with each other,
an impulse to one part is communicated more readily to the others.
he convoluted form of the cochlea serves also the purpose of afford-
in a small space a considerable extent of surface required for the
nsion of the nervous fibres.

he object which nature has sought to attain in the cochlea seems
e the spreading out of the nervous fibres upon a solid lamina which

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Mr. Pilcher (in his work on the Structure and Diseases of the Ear) has collected accounts
merous cases of congenital deafness, in which malformations of the internal ear, par-
rly of the semicircular canals, were found to exist.

The otolites of the osseous fishes have a structure similar to that of the enamel of teeth.
of the zander (Perca lucioperca), for example, are formed of laminæ with a zone-like
gement, in which a regular fibrous structure is at once evident. If laminæ of these
ground thin be treated with muriatic acid, they are seen to be constituted of acumi-
bodies, exactly like those which I have described as existing in the enamel before it
ecome hardened. (Poggendorf's Annal. 38.)

should communicate with the solid walls of the labyrinth and cranium, at the same time that it is in contact with the fluid of the labyrinth; and which, besides exposing the nervous fibres to the influence of sonorous undulations by two media, should be itself insulated by fluid on either side. In accordance with this view, we can explain all the acoustic provisions of the cochlea.

The connection of the lamina spiralis with the solid walls of the labyrinth adapts the cochlea for the perception of the sonorous undulations propagated by the solid parts of the head and the walls of the labyrinth. This use of the cochlea has been previously pointed out by Professor E. H. Weber. (*Annot. Anatomicæ et Physiologicæ. Lips.* 1834.) The membranous labyrinth of the vestibule and semicircular canals is suspended free in the liquor Cotunnii, and is evidently destined more particularly for the perception of sounds through the medium of that fluid, whether the sonorous undulations are imparted to the fluid by the intervention of the cranial bones, as in fishes and in man, when sounding bodies are brought into communication with his head or teeth, or through the fenestræ. The membranous labyrinth is certainly exposed to the influence of the resonance of the bony parietes of the labyrinthic cavity; for sonorous undulations in water are, as I have shown, heard with greatest intensity in the vicinity of solid walls; but yet it remains strictly true that the membranous labyrinth is acted on immediately only by the undulations of a fluid. The spiral lamina on which the nervous fibres are expanded in the cochlea is, on the contrary, continuous with the solid walls of the labyrinth, and receives directly from them the impulses which they transmit. This is an important advantage; for the impulses imparted by solid bodies have, *cæteris paribus*, a greater absolute intensity than those communicated by water.

This is not, however, the sole office of the cochlea; the spiral lamina, as well as the membranous labyrinth, receives sonorous impulses through the medium of the fluid of the labyrinth from the cavity of the vestibule and from the fenestra rotunda. The lamina spiralis of man and Mammalia is indeed much better calculated to render the action of these undulations upon the auditory nerve efficient than the membranous labyrinth; for, as a solid body insulated by a different medium, it is capable of resonance.

Lastly, it may be observed that the object of the fibres of the nerve being spread out singly upon the lamina spiralis is evident. In the first place, it insures a more complete participation of the fibres in the impulses communicated by the solid parts of the cochlea; and, secondly, the intensity with which the sonorous undulations are communicated to a body is proportionate to the extent of surface over which they can act on it. Thus, when a sound is excited in water, and is conducted to the stopped ears by means of a rod, the intensity of the sound heard increases with the depth to which the rod is immersed in the water, or with the extent in which it is in contact with the surface of the water.

CHAPTER III.

OF THE ACTIONS OF THE AUDITORY NERVE.

Influence of the mind in hearing.—The perception of the direction of sounds is not a faculty of the sense of hearing itself, but is an act of judgment which founds it on experience previously acquired. From the modifications which the sensation of sound undergoes according to the direction in which the sound reaches us, the mind infers the position ıe sounding body. The only true guide for this inference is the ɜ intense action of the sound upon one than upon the other ear. even here there is room for much deception by the influence of re- ion, or resonance, and by the propagation of sound from a distance out loss of intensity through curved conducting-tubes filled with By means of such tubes, or of solid conductors which convey the rous vibrations from their source to a distant resonant body, sounds be made to originate apparently in a new situation.

he direction of sound may also be judged of by means of one ear ; the position of the ear and head being varied, so that the sonorous ılations at one moment fall upon the ear in a perpendicular direc- at another moment obliquely.

'hen neither of these circumstances can guide us in distinguishing lirection of sound, as when it falls equally upon both ears, its source g, for example, either directly in front or behind us, it becomes im- ible to determine whence the sound comes: this, which has been onstrated by Venturini's experiments, (*Voigt's Magazin*, Bd. 2,) necessary consequence of physical laws. Undulations give not ɜly the impulses of condensation in one direction, but that of rare- on in the opposite; and, when several undulations succeed one her, these impulses in opposite directions regularly alternate. If, ɜfore, the nerves were capable of distinguishing the direction of ılses, no means would thus be afforded for determining whether a ıd came in one direction or in the opposite.

entriloquists take advantage of the difficulty with which the direc- of sounds is recognised, and also of the influence of the imagination ' our judgment, when they direct their voice in a certain direction, at the same time pretend themselves to hear the sounds coming ı thence.

he distance of the source of sounds is not recognised by the sense f, but it is inferred from their intensity. The sound itself is always ɜd but in one place, namely, in our ear; but it is interpreted as ing from an exterior soniferous body. When the intensity of the e is modified in imitation of the effect of distance, it excites the of its originating at a distance; and this also is taken advantage of 'entriloquists.

he mind has, however, the power of influencing the act of sensation f,—of voluntarily increasing its intensity, as in "listening." By faculty of attention we can distinguish one sound out of several or ıy others,—can follow the tones of one instrument in a full orchestra. /hen two persons address their speech to our opposite ears simulta- ısly, the two impressions conveyed to the sensorium become mixed; it is only by great exertion of the attention, and by the aid of a ırence of tone of the two voices, that we are enabled to follow the ıds of one exclusively, disregarding those of the other, which are ı heard as a more or less indistinct murmur. When the activity of sensorium is not directed to the impressions communicated to it by auditory nerves, sounds that exist are not heard; or, what frequently pens, a sound may be so faint, that, on account of the mind being ted to other objects, it is for a moment disregarded, but is heard as soon as the attention is recalled to it. Similar phenomena are observed to occur in the case of the other senses.

Acuteness of hearing.—The sense of vision may vary in its degree of perfection as regards either the faculty of adjustment to different distances, the power of distinguishing accurately the particles of the retina affected, sensibility to light and darkness, or the perception of the different shades of colours. In the sense of hearing there is no parallel to the faculty by which the eye is accommodated to distance, nor to the perception of the particular part of the nerve affected; but just as one person sees distinctly only in a bright light, and another only in a moderate light, so in different individuals the sense of hearing is more perfect for sounds of different pitch: and just as a person, whose vision for the forms of objects, &c. is acute, nevertheless distinguishes colours with difficulty, and has no perception of the harmony and disharmony of colours, so one, whose hearing is good as far as regards the sensibility to feeble sounds, is sometimes deficient in the power of recognising the musical relation of sounds, and in the sense of harmony and discord; while another individual, whose hearing is in other respects imperfect, has these endowments.

Many persons, whose hearing is good, are incapable of perceiving very high or acute tones; Dr. Wollaston observed several instances of this kind: while deaf persons sometimes hear shrill sounds very well. Among the causes of this latter condition is, as we have before remarked, a state of too great tension of the membrana tympani, in whatever way produced. Many deaf people hear sounds, which are not very intense, better when a loud noise prevails at the same time. Of this condition, *paracusis Willisiana*, two instances are described by Willis: one was that of a person who could only maintain a conversation when a drum was beat near him; in the other case, the individual could hear only while a bell was ringing. Similar cases have been observed by Holder, Bachmann, Fielitz; (see *Muncke, in Gehler's Physic. Wörterbuch*, iv. 2, p. 1220,) they are, perhaps, to be attributed to a state of torpor of the auditory nerve, which requires to be roused before it can exercise its functions. Sometimes, however, the circumstance of a deaf person hearing particular sounds during a great noise as well as other people who are not deaf, may arise from his being much less disturbed by the noise than they. It is thus that a deaf person explains the fact that, when travelling in a close carriage, he can take a part very well in conversation. His companions, he says, do not then hear each other's voices better than he, because the noise of the carriage is heard much more loudly by them. Excessive acuteness of hearing, *hyperacusis*, arises from a state of too great excitability of the auditory nerve, and corresponds to the photophobia of vision.

The causes on which the defect of a musical ear depends, are unknown. A person who is deficient in the sense of musical intervals, harmonies, and discords, will be a bad singer, though he have a good voice.

Sympathies of the auditory nerve.—Irritation or excitement of the auditory nerve is capable of giving rise to movements in the body, and to sensations in other organs of sense. In both cases it is probable that the laws of reflexion through the medium of the brain come into play. An intense and sudden noise excites in every person closure of the eyelids, and in nervous individuals a start of the whole body. The secondary sensations induced by impressions on the sense of hearing are principally seated in the nerves of touch, or common sensation. A sudden noise excites in persons of excitable nervous system an unpleasant sensation, like that produced by an electric shock, throughout the body, and sometimes a particular feeling in the external ear. Various of sounds, such as the friction of paper, or scratching of glass, in many people a disagreeable feeling in the teeth, or, indeed, a tion of cold trickling through the body. Intense sounds are said to the saliva collect in the mouth in some people.*

ie sense of hearing may in its turn be affected by impressions on other parts of the body; but this is observed especially in diseases dominal viscera, and in febrile affections. Here, also, it is probable the central organs of the nervous system are the media through h the impression is transmitted.

SECTION III.

OF THE SENSE OF SMELL.

CHAPTER I.

THE PHYSICAL CONDITIONS FOR THE PERCEPTION OF ODOURS.

sense of smell ordinarily requires for its excitement to a state of ity the action of external matters, which produce certain changes ie olfactory nerve; and this nerve, like that of taste, is susceptible infinite variety of states dependent on the nature of the external ulus.

e first condition essential to the sense of smell is the existence of cial nerve, the changes in whose condition are perceived as sensa- of odour; for no other nerve is capable of these sensations, even gh acted on by the same causes. The same substance which ex- the sensation of smell in the olfactory nerves causes a peculiar in the nerve of taste, and may produce an acrid and burning sen- n in the nerves of touch. The opinion of Kant, that smell is dis- taste, appears to me to be incorrect.

he second condition of smell is a peculiar condition of the olfactory e, or a peculiar change produced in it by the stimulus or odorous tance.

he material causes of odours are, in the case of animals living in ir, substances suspended in a state of extremely fine division in the sphere; or gaseous exhalations, often of so subtile a nature that they be detected by no other re-agent than the sense of smell itself. In s the odorous matters are contained in the water; but in what form, hether dissolved in the same manner as the gases absorbed by er,—is uncertain. The solution of these matters in water is clearly eason for denying the sense of smell to fishes, or for placing the e of taste in their nares; for the essential characteristic of the sense nell consists, not in the gaseous nature of the odours, but in the ial sensibility of certain nerves, and in its difference from the sen- ity with which the nerves of taste are endued. The matters of

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Many other examples of sympathy of this kind have been collected by Tiedemann, schrift f. Physiol. B. i. H. 2,) and Lincke (op. cit. p. 567).

odours, also, must in all cases be dissolved in the mucus of the mucous membrane before they can affect the olfactory nerves, and their state in the mucus must be the same as that in which they are contained in water. On the other hand, the nerve of taste is not acted on solely by liquid and solid matters; gaseous substances also are sometimes tasted when, like sulphurous acid, and many other gaseous bodies, they are capable of being dissolved in the fluid covering the tongue. It may, therefore, be easily conceived that the very same principle will produce different sensations in the organs of smell and taste; in the former the sensation of a particular odour, in the latter that of a peculiar taste. The observation of Treviranus, that in animals living in the air the organ of smell is comparable to a lung, in fishes to a gill or branchia, is, to a certain extent, correct and ingenious; but it would be as erroneous to suppose that the odorous matters dissolved in water must be converted into the gaseous state before acting on the olfactory nerve, as that the gases absorbed and dissolved in the water must be restored to the form of gases in the branchiæ before being taken up into the blood. The state in which these gases are contained in the blood is, indeed, the same as that in which they exist in the water. Lastly, it is to be observed that the olfactory nerves of fishes are identical with the olfactory nerves of all other animals; they arise from the same parts of the brain, the lobi olfactorii, which, even in Mammalia, exist in the form of the olfactory bulb.

A further condition necessary for the perception of odours is, that the mucous membrane of the nasal cavity be moist; for, as we have already observed, the moisture of the mucous surface is the vehicle through the medium of which the odorous matters are more immediately applied to the nerves. When the Schneiderian membrane is dry, the sense of smell is lost; thus, in the first stage of catarrh, when the secretion of mucus within the nostrils is lessened, the faculty of perceiving odours is either lost, or rendered very imperfect.

In animals living in the air, it is also requisite that the odorous matters should be transmitted in a current through the nostrils. This is effected by the respiratory movements: hence we have voluntary influence over the sense of smell; for by interrupting respiration we prevent the perception of odours, and by repeated inspirations render their impression more intense.

In aquatic animals this influence over the sense by voluntary movement does not exist; for in them the nostrils are generally closed posteriorly, and do not communicate directly with the respiratory organs. Yet even here the effect which the current through the nostrils would produce is attained in another way,—namely, by the constant current into the mouth, and from the branchial apertures, which is maintained by the movements of the branchial operculum.

CHAPTER II.

OF THE ORGAN OF SMELL.

In Mammalia the nasal apparatus includes the labyrinth of the ethmoid bone, the turbinated bones, and the accessory sinuses opening into the nasal cavity. The development of surface in the inferior turbinated bone is very remarkable. The most peculiar forms are presented on the one hand by the Ruminantia, Solidungula, &c.; on the other, by the Carnivora. In the former orders, the inferior turbinate bone is, at its line of attachment, a simple lamina, which afterwards divides into an upper and a lower lamella, of which the first is rolled upwards like a scroll of paper, the other

iwards in the same form. In Carnivora the lamina divides into branches, which
off side branches, much in the manner of the arbor vitæ of the cerebellum. Com-
l with these states of development, the condition of the turbinated bones in the
in subject appears quite rudimentary. The organs discovered by Stenson main-
a communication between the nasal cavity and mouth at the situation of the
ien incisivum in many Mammalia. These canals must not be confounded with
artly membranous, partly cartilaginous, tube observed by Jacobson, which lies
ie floor of the nostrils, between the vomer and the mucous membrane, and
iunicates with the canals of Stenson. The function of these parts is not known.*

he accessory cavities or sinuses communicating with the nostrils
i to have no relation to the sense of smell. Air impregnated with
vapour of camphor was injected by Deschamp into the frontal sinus
ugh a fistulous opening, and Richerand injected odorous substances
the antrum of Highmore; but in neither case was any odour per-
ed by the patient. Nature seems to attain nearly the same object
ther she fills the cavities of bones with air or with fat; in either
she renders the bones lighter than they would be were they solid
ughout. In birds many bones are filled with air; those of the
k through the medium of the lungs, those of the head through the
achian tube: in man certain bones of the head only contain air,
ely, the mastoid process of the temporal bone, and the bones
iding the nasal cavity. The mucous membranes both of the nares,
of the sinuses opening into them, presents the ciliary motion in all
ials.

ie process by which the stimulus is conveyed to the nerve, in the
s hitherto considered so complex, is here very simple. The
ous matters suspended in the air in the form of vapour, or some-
s, perhaps, of a very fine powder, are brought into contact with
entient mucous surfaces by the current to which the respiratory
ements give rise. A current of air from within outwards some-
s excites the sensation of odour, as in the case of odorous sub-
es being developed in the respiratory organs, or when such
ers developed in the digestive organs are expelled upwards by
tation.

only remains for us here to consider the mode in which the per-
on of odours may be rendered more acute or prevented. We are
to avoid the perception of unpleasant odours, by interrupting in-
tion through the nose. By inspiring the odorous vapours through
iostrils with greater force, or by repeating the inspiration frequently,
an render their impression greater. In tracking by the scent, ani-
seek the part of the atmosphere containing the odorous matters by
ing rapidly-repeated inspirations in different directions, and then
w the scent to its source by the same means. The perception of the
ous matters also may be favoured by the wind. In this way rumi-
animals, without tracking the scent, are believed frequently to
eive odours developed at a distance.

ides the sense of smell, the nasal cavities are also endowed with common sensi-
by the nasal twigs of the first and second divisions of the fifth nerve. Hence
nsations of cold, heat, itching, tickling, and pain, and the sensation of tension
ssure in the nostrils. That these nerves cannot perform the function of the

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e Rosenthal in Tiedemann's Zeitschrift f. Physiol. ii. p. 289. With reference to the
ded absence of olfactory nerves in the Cetacea, see page 589.

olfactory nerves is proved by the cases in which the sense of smell is lost; while the mucous membrane of the nose remains susceptible of the various modifications of common sensation or touch. It is often difficult to distinguish the sensation of smell from that of mere feeling, and to ascertain what belongs to each separately. This is the case particularly with the sensations excited in the nose by acrid vapours, as of ammonia, horseradish, and mustard, &c. which resemble much the sensations of the nerves of touch; and the difficulty is the more apparent when it is remembered that these acrid vapours have nearly the same action upon the mucous membrane of the eyelids.

CHAPTER III.

OF THE ACTION OF THE OLFACTORY NERVES.

Animals do not all equally perceive the same odours; the odours perceived by a herbivorous animal and by a carnivorous animal are different. The cause of this difference must lie in the endowments of the central parts of the olfactory apparatus. The Carnivora have the power of detecting most accurately by the smell the special peculiarities of animal matters, and of tracking other animals by the scent; but have apparently no sensibility to the odours of plants and flowers. Man is far inferior to carnivorous animals in respect of the acuteness of smell, but his sphere of susceptibility to odours is more uniform and extended.

Opposed to the sensation of an agreeable odour is that of a disagreeable or disgusting one, which corresponds to the sensations of pain, dazzling and disharmony of colours, and dissonance, in the other senses. The cause of this difference in the effect of different odours is unknown, but thus much is certain, that odours are pleasant or offensive in a relative sense only, for many animals pass their existence in the midst of odours which to us are highly disagreeable. A great difference in this respect is, indeed, observed amongst men. Many odours generally thought agreeable are to some persons intolerable: the smell of burnt horn is to many persons unpleasant; to others, who are not at all fanciful, agreeable. To many individuals mignonette does not smell very sweet; but rather herb-like, as Blumenbach observes, and as I experience in my own person. We have no exact proof that a relation of harmony and discord exists between odours, as between colours and sounds; though it is probable that such is the case, since it certainly is with regard to the sense of taste. It is also not certain that sensations of odours continue after the impression of the odorous matter has ceased, though we can scarcely imagine that such is not the case. It is difficult to ascertain this point by direct observation; the cadaverous odour, which is frequently retained in the nose very long after post-mortem examinations, cannot be regarded as a proof, since it probably arises from some of the odorous matter remaining dissolved in the mucus of the nostrils.

The sensations of the olfactory nerves, independent of the external application of odorous substances, have hitherto been little studied. It has been found that solutions of inodorous substances, such as salts, excite no sensation of odour when injected into the nostrils. The friction of the electrical machine is, however, known to produce a like that of phosphorus. Ritter, too, has observed, that when galvanism is d to the organ of smell, besides the impulse to sneeze, and the tickling sensa- smell like that of ammonia was excited by the negative pole, and an acid odour positive pole; whichever of these sensations was produced, it remained constant g as the circle was closed, and changed to the other at the moment of the circle opened. Frequently a person smells something which is not present, and which persons cannot smell; this is very frequent with nervous people, but it occa- y happens to every one. In a man who was constantly conscious of a bad the arachnoid was found after death, by MM. Cullerier and Maignault, to be with deposits of bone; and in the middle of the cerebral hemispheres were scro- cysts in the state of suppuration. Dubois was acquainted with a man who, fter a fall from his horse, which occurred several years before his death, believed smelt a bad odour.

ether substances which have a strong odour would, when introduced into the ation, excite the olfactory nerve to the perception of the odour, has not been ascer- experimentally.

senses are so intimately connected with the instinctive operations of the animal ny, as are smell and taste. Odours excite powerfully the sexual impulse of ls, and, by their influence on the brain and spinal cord, give rise to the actions ted with that impulse.*

SECTION IV.

OF THE SENSE OF TASTE.

CHAPTER I.

OF THE PHYSICAL CONDITIONS FOR TASTE.

conditions for the perception of taste are:—1, the presence of erve with special endowments; 2, the irritation of this nerve by apid matters; 3, the solution of these matters in the secretions of rgan of taste. The mode of action of the substances which excite can hardly be mechanical, any more than that of odorous matters; must rather consist in the production of a change in the internal ition or material composition of the nerve by matters in solution; according to the difference of these matters, an infinite variety of ges of condition, and consequently of tastes, may be induced in the . It cannot, however, be affirmed that the excitement of taste by chanical impression on the nerve of taste is absolutely impossible. sure, traction, pricking, and friction excite in the tongue only varie- of common sensation, it is true; but Henle has observed that a small nt of air directed upon the tongue gives rise to a cool saline taste, that of saltpetre, and the mechanical irritation of the fauces and e produces the sensation of nausea, which has no affinity to the us modifications of touch or common sensation, but is so allied to that it cannot be separated from it.† Electricity is the only im- erable principle which excites taste.

a general rule, the matters to be tasted must either be in solution soluble in the moisture covering the tongue; insoluble substances

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n account of the facts known with regard to the sense of smell was published by H. ot at Paris, in 1821, under the title of "Osphresiologie."

he translator has shown, in a preceding page, that a distinct sensation of taste, ar to that caused by electricity, may be produced by a mechanical stimulus ed to the papillæ of the tongue.

produce merely sensations of touch. It is a matter of doubt whether the mere contact of a moist animal substance used as food with the vital organ of taste can excite its specific sensation independently of the matters contained in solution within the mass of food. Some gases, however, as sulphurous acid gas, are capable of exciting the sense of taste.

For a perfect action of a sapid, as of an odorous substance, it is necessary that the sentient surface should be moist. There are no other means for conducting the stimulus to the nerve in this sense than the mucous secretion of the tongue. Hence the investigation here, as in the case of the sense of smell, is rendered very simple.

CHAPTER II.

OF THE ORGAN OF TASTE.

The sense of taste has its seat in the fauces, but more especially in the tongue, which, nevertheless, is in many animals more important as an organ of deglutition. On account of this latter circumstance, the numerous varieties of form presented by the tongue in the animal series have little interest with reference to the sense of taste, and need not here engage our attention.

In man the contact of the finger or any solid body with the soft palate excites the sensation of nausea, which might certainly be explained by supposing it to result from the impression being reflected upon the nerves of taste; but the sensibility of the palate to sapid substances is proved by the experiments of Dumas, Autenrieth, Horn, Lenhossec, Treviranus, and Bischoff; and when I rub upon the velum palati a small piece of Swiss cheese, I perceive distinctly its taste in the palate. It has been demonstrated by the experiments of Dupuytren, Mayo, and myself, that the ninth, or hypoglossal, is the motor nerve of the tongue, and the lingual branch of the fifth the sensitive nerve; for these experiments have proved that irritating the hypoglossal nerve by galvanism, or mechanically, excites muscular contractions in the tongue, while division of the lingual nerve gives rise to violent pain. Experiments made to ascertain whether the lingual branch of the fifth nerve has any motor power require to be performed with the same precautions as experiments upon the roots of the spinal nerves. The nerve must first be divided, and the peripheral portion thus cut off from its communication with the central organs of the nervous system alone irritated. If the lingual branch of the fifth nerve be subjected to irritation, while yet in connection with the brain and spinal cord, muscular contractions may be excited in the tongue and other parts by reflexion, as I have myself once recently observed.

With respect to the controversy as to whether the lingual branch of the fifth, or the glossopharyngeal nerve, be the nerve of taste; we have already stated the principal arguments (see page 590). (See also *Bischoff, in the Encyclop. Wörtbuch der Med. Wissenchaft.*) Professor R. Wagner, (*Froriep's Notiz.* 1837, *n.* 75,) has adopted Panizza's view, on the ground of physiological as well as anatomical facts; Valentin and Bruns also have arrived at a similar conclusion from the results of their experiments; while those of Kornfeld, Gurlt, and myself, favour the opposite opinion,—

', that the lingual branch of the fifth is the principal nerve of taste. (See *Mül-* '*chiv*. 1838, p. cxxxiv.; and *Valentin's Report*, 1837, p. 221.) I cannot regard in's experiments as conclusive proofs of the sense of taste residing in the glos- yngeal nerve, since a fortnight after the division of the nerve the animal is to have begun to taste again. This period is so short as even to render it pro- that taste was never lost. Dr. Alcock's experiments (*Med. Gaz*. 1836, Nov.; *ıblin*, vol. x. p. 260) have not decided the question. The perception of bitter ıces was not lost after division of the glossopharyngeal nerve; it was lost at the r part of the tongue only, when the lingual nerve was divided. He believes ıse of taste to be seated not only in the glossopharyngeal nerve and the lingual of the fifth, but also in the palatine branches of the fifth; the experiments ıspect to the latter nerves were not decisive.

ɜ pathological observations, showing loss of taste accompanying of the fifth nerve, as in the cases detailed by Parry, Bishop, and ›erg, are very important. In Mr. Bishop's case, the pressure of a ng upon the divisions of the fifth nerve was productive of loss of in the corresponding half of the tongue. (*Med. Gaz*. 1833; and *ır's Archiv*. 1834, p. 132.) The case related by M. Romberg *ler's Archiv*. 1838; *Heft* iii.) is that of a person in whom taste and ıon sensibility were lost in one half of the tongue; and here, also, ommencement of the third branch of the fifth nerve was found on by a small tumour, while the glossopharyngeal nerve was ıy.

appears to me certain, both from the experiments of Magendie, , Kornfeld, and myself, as well as from the pathological observa- of Parry, Bishop, and Romberg, that the lingual branch of the fifth principal nerve of taste of the tongue; but I do not regard it as ːd that the glossopharyngeal nerve has no share in the perception ıte at the posterior part of the tongue and in the fauces. M. Rom- ascribes to it the sense of nausea, by which the entrance into the tive organs is guarded.

CHAPTER III.

ΓHE SENSATIONS OF TASTE AND THE ACTIONS OF THE GUSTATORY NERVES.

is quite impossible to explain the various sensations of taste. The ːe of the essential quality of taste, by which it is distinguished from , common sensation, sight, and the sensation of sound, is, like the ɾe of every other sensation, quite inexplicable. Of the essential ty of blue, for example, we can form no further conception; it can be perceived as a sensation; and we must remain contented with ;nowledge that the different nerves of sense enjoy special properties, perceiving colours,—blue, for example; another sounds, a third rs, and so on. But the causes on which the differences in the ıus sensations of one and the same nerve depend may possibly be 'tained, and in the cases of vision and hearing they are already vn. We know that one sound differs from another in proportion ɘ difference in the number of undulations producing them; and that ıumber of undulations of the imponderable ether of light, within a given time, is different for each colour. In the cases of the senses of taste and smell, however, we are far from having such a theory to explain the varieties of sensations. Bellini tried to elucidate the great variety in the sensations of taste by means of the old hypothesis of the different form of the ultimate molecules of bodies,—a theory which cannot be refuted, but which is quite as incapable of proof. At the period when everything was accounted for by chemical polarities, it was customary to make application of this hypothesis also to explain the phenomena of taste.

Besides the sense of taste, the tongue is endued with a very delicate and accurate touch, which renders it sensible of the impressions of heat and cold, itching, pain, and mechanical pressure, and consequently of the form of surfaces.

The tongue may lose its common sensibility, and still retain the sense of taste, and *vice versâ*. (*Müller's Archiv.* 1835, p. 139.—*Medical Gazette*, *Oct.* 1834.) This fact renders it probable that the nervous conductors for these two different sensations are distinct, just as the nerves for smell and common sensibility in the nostrils are distinct. It will be easily conceived that the same nervous trunk may contain fibres differing very essentially in their specific properties. Facts detailed in a previous page prove that the lingual branch of the fifth nerve is the seat of sensations of taste; but it is also certain, from the marked manifestations of pain to which its division in animals gives rise, that it is a nerve of common sensibility. The hypoglossal, or ninth nerve, also is endowed with sensibility in addition to its motor power (see page 597).

Many substances having odour as well as taste, their simultaneous action upon the two senses gives rise to a more or less mixed sensation. The sensation of taste may, however, in such a case be isolated from that of smell by closing the nostrils. Many fine wines lose much of their apparent excellence if the nostrils are held close while they are drunk.

It would appear, from the experiments of Horn, (*Über den Geschmacks-sinn des Menschen.* Heidelberg, 1835,) that some substances excite a different taste, according as they are applied to different papillæ of the tongue; an observation which would seem to afford an explanation of the difference often perceived between the flavour first excited by some substances, and those which they leave behind them upon the tongue. Horn instituted experiments with a great number of substances, and found that a part of them tasted the same in all regions of the tongue's surface; while others had very different tastes, according as they were applied in the neighbourhood of the papillæ filiformes, or of the papillæ vallatæ.

Very distinct sensations of taste are frequently left after the substances which excited them have ceased to act on the nerve; and such sensations often endure for a long time, and modify the taste of other substances applied to the tongue afterwards. After I have chewed a piece of the root of sweet flag (acorus calamus), milk and coffee have to me a sourish taste; the taste of sweet substances spoils the flavour of wine, the taste of cheese improves it. There appears, therefore, to exist the same relation between tastes as between colours, of which those that are opposed or complementary render each other more vivid, though no general principles governing this relation have been discovered in the case of tastes. In the art of cooking, however, attention has at all times been paid to the consonance or harmony of flavours in their combination or order of succession, just as in painting and music the fundamental principles of harmony have been employed empirically while the theoretical laws were unknown.

Frequent and continued repetition of the same taste renders the perception of it less and less distinct, in the same way that a colour becomes and more dull and indistinct, the longer the eye is fixed upon it. ınd white wine can at first be distinguished by their flavour when /es are bound; but, after frequently tasting first one and then the , it soon becomes impossible to discriminate between them.

simple contact of a sapid substance with the surface of the gustatory organ ise frequently to a very indistinct sensation of taste, and sometimes to none at he sensation is, on the contrary, very much heightened by the compression, ı, and motion of the substance to be tasted between the tongue and palate. The of this may be either that the impression is rendered more intense when com- with a mechanical impetus, as is the cause in the perception of odours; or that itability of the sentient points of the tongue's surface soon becomes exhausted, t motion is necessary to bring the foreign substance into relation with fresh f the nerve. The hypothesis recently proposed by Raspail that a reciprocal is here excited between the two living surfaces brought into contact with each s very improbable, since the friction of the substance to be tasted upon the by any other means, without the contact of the tongue and palate, has the ffect.

ısations of taste, independent of the application of sapid substances, been hitherto little observed. We have instances of these sensa- however, in the nausea produced by mechanical irritation of the f the tongue and soft palate; in the saline taste observed by Henle excited by the impression of a small current of air; and in the ınd alkaline tastes to which the application of galvanism by means plates of different metals to the tongue give rise. Reasons which r improbable the opinion that this last phenomenon is due to de- osition of the salts of the saliva are stated at page 623; moreover, me tastes can be excited by a mechanical stimulus.

e reaction of the sense of taste seems capable of being excited also gh the medium of the blood, in the same way that the sense of ı is affected so as to produce flickering before the eyes, &c. by the ıce of narcotic substance in the circulation. M. Magendie has ved that dogs, into whose veins milk has been injected, lick their ith their tongue as if they tasted. It is probable that the sense te is sometimes modified, and peculiar sensations of taste excited, ternal changes in the condition of the nerves; but it is difficult to guish such phenomena from the effects of external causes, such ınges in the nature of the secretions of the mouth.

SECTION V.

OF THE SENSE OF TOUCH.

E sense of touch is not confined to particular parts of the body of extent, like the other senses; on the contrary, all parts capable of iving the presence of a stimulus by a sensation of mere touch, or a fication of the sensations of pain or pleasurable feeling, or of heat d, are the seat of this sense. The external causes exciting these tions are mechanical, chemical, or electrical influences, and changes nperature. The sense of touch, or common sensibility, extends ghout the whole animal and organic system, though its acuteness s exceedingly in different parts. Even the special organs of the senses are endowed with common sensibility, and hence are supplied with other nerves besides that of the particular sense peculiar to them. The nerves of touch are the posterior ganglionic roots of the nerves of the vertebral or spinal system, which includes some of the cerebral, and all the spinal nerves. The sensitive fibres contained in these posterior ganglionic roots go, for the most part, to compose with other fibres the nerves of animal life; but a smaller part of them assist in forming the nerves of organic life, endowing the latter nerves with their obtuse sensibility, the former with their vivid sense of touch. The so-named common feeling (cœnæsthesis) is not a peculiar sense, but merely the common sensibility of the internal parts of the body, which is capable of endless modifications, from the feeling of fatigue to that of pain in disease, and from the feeling of ease to that of pleasurable sensations and tickling in the state of heath.

Parts endowed with the sense of touch and common sensibility. Organs of touch.—Touch, in its more limited sense, does not differ essentially from the sensibility more generally enjoyed by the textures of the body: its peculiarity depends solely on the relation of the sensitive organ to the external world. Every part of the surface endowed with sensibility has the sense of touch, inasmuch as it is capable of perceiving the contact of external bodies. It becomes especially an organ of touch, when its sensibility is very delicate and it is endowed with motion. The organs of touch are therefore the whole extent of the skin, but more especially the hands, the tongue, the lips, (particularly in feline animals, and seals and walruses, where they are provided with vibrissæ, the pulps of which are very sensitive, and plentifully supplied with nerves,) the proboscis and mouth of some animals, the tentacles of the Mollusca, the antennæ and palpi of insects, and the finger-like processes of the pectoral fins of the Triglæ, the nerves of which arise from a series of special lobes or enlargements of the spinal cord. The part developed for the purpose of touch in the skin is the corpus papillare, consisting of small elevations of the surface of the cutis, visible by the aid of a lens, which are invested by a sheath of the rete Malpighii, and contain the terminations of the nerves.*

The minute description of the organs of touch in different animals belongs to comparative anatomy.

The parts of the body in which the sense of touch or common sensibility has its special seat, are certain regions of the central organs of the nervous system, and the vertebral or spinal system of nerves; and by these it is imparted to most organs of the body.

There are parts of the nervous centres which appear to be perfectly insensible; for example, the surface of the hemispheres, which, there have been frequent occasions to observe, both in man and animals, may be wounded without the production of any pain. In cases where, after injuries to the head, it has been necessary to remove partially destroyed and projecting portions of brain, while the patient was in a state of consciousness, the operation has never caused pain, or even been felt.

Other parts of the nervous centres, on the contrary, are very sensible; but the sensations of which they are susceptible are not uniformly the same. When the parts of the central organs connected with the sense of vision are irritated, appearances of light are perceived. It is an old observation, that pressure upon the brain in the human subject gives rise to the perception of luminous appearances and flashes like lightning. But there are other parts of the brain which are susceptible of the varieties of common sensation; for although pain in the head is in instances seated merely in the nerves of the exterior investments brain, yet the possibility of such sensations, as of tension or pain, seated in the brain itself, is shown by cases of chronic affections it organ, where the patient has had a more or less distinct conness from his sensations of the seat of the disease.*

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* See Breschet and Roussel de Vauzème, Ann. d. Sc. Nat. 1834, t. i. p. 167.

e spinal portion of the encephalon and the spinal cord are susle only of the modifications of common sensation, which are perd both at the situation where they are excited, namely in the le line of the back, and in the external parts to which the spinal s are distributed, having there the character either of pain or of eeping of insects, "formicatio." The local sensations in the back metimes unattended with those in the peripheral parts, and *vice* . The cause of these remarkable differences is unknown.

laws regulating the production of sensation in nerves, by irritation applied to elves, have been fully considered in the book on the physiology of the nerves. remains for us, therefore, here to speak of the sensations caused by stimuli d to their peripheral extremities.

horny tissue and teeth are perfectly destitute of sensibility, though their or pulp is supplied with nerves as well as with vessels. The sensation in th produced by the contact of acids must therefore be regarded as an affection ir pulp; and it is easy to conceive how the acid may be conducted to that part capillary dental tubes, whether we suppose it to act first on the ivory of the where it is uncovered, or to reach the ivory through the clefts which are so frein the enamel.

dons, cartilages, and bones are in the healthy state void of sensibility, as Haller d by numerous experiments. Haller's experiments also seemed to show that the steum is insensible. The dura mater, however, appears to constitute an exception; t least certain that it is supplied with nerves. In the state of disease, however, nes, like the viscera of the chylopoetic system supplied by the sympathetic, e the seat of severe pain.†

sensibility of the muscles is much less than that of the skin, a fact which is nt in the operation of acupuncture. The skin itself varies very much in different in the degree of its sensibility, which is probably proportionate to the number of us fibres distributed in it. An account of Professor E. H. Weber's observations re to this subject has been given at page 546. At the same parts of the surface, two small bodies applied at a very little distance from each other were recogas separate bodies, the differences of temperature, and the weight of bodies ed, were also, according to Professor Weber's observations, most accurately nised. The weight of bodies produced a greater impression at these parts; y placed upon the volar surface of a finger seemed heavier, its pressure was ived with greater intensity, than when it was laid upon the skin of the ead.

he sensibility of the mucous membranes is very great in the respiraapparatus, in the organs of sense, and in the generative organs, re they are supplied by nerves of animal life; while in the innal canal the sensibility of the analogous membrane is very slight ne normal condition, though in disease it may be exaggerated to t intensity. The external and internal tegumentary system differ each other, moreover, in the circumstance that the tingling sensa-, or "formication," which is frequently excited in the skin by in-

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See Nasse, über Geschwülste im Gehirn, p. 26; and Abercrombie, on Diseases of Brain, translated into German by De Blois. Bonn, 1821.

For an account of the numerous experiments which have been instituted relative to this tion, see Haller's Element. Physiol. iv. p. 271–289.

ternal causes, and particularly by affections of the spinal cord, appears to be never felt in the mucous membranes.

Various modifications of common sensation.—The sensations of the common sensitive nerves have as peculiar a character as those of any other organ of sense. The sense of touch renders us conscious of the presence of a stimulus, from the slightest to the most intense degree of its action, neither by sound, nor by light, nor by colour, but by that indescribable something which we call feeling, or common sensation, the modifications of which often depend on the extent of the parts affected. The sensation of pricking, for example, informs us that the sensitive particles are intensely affected in a small extent; the sensation of pressure indicates a slighter affection of the parts in a greater extent, and to a greater depth. It is by the depth to which the parts are affected, that the feeling of pressure is distinguished from that of mere contact.

The sensation of a blow or shock arises from a sudden change being produced in the state of the nerves by an external or internal influence,—namely, by the mechanical influence of a solid body, or by an electric discharge. A sudden discharge of nervous principle from the brain also, as at the moment of fright, is sometimes productive of the sensation of a shock or blow. The peculiarity of this sensation, therefore, depends in no way upon the mechanical action of the foreign body.

In some other senses, a rapid succession of impulses produces peculiar sensations, which vary in their quality according to the number of the impulses communicated to the nerve within a given time,—such, at least, is the case with the sense of hearing, and, perhaps, also with that of vision,—while on the senses of taste and smell this mode of excitement has no such effect. How is it with the sense of touch?

A rapid succession of equal impulses, such as produces the sensation of sound in the organ of hearing, is felt by the nerves of touch as a thrill or tremor. If the impression of the vibrations be more intense, and the part which is the seat of it very sensible,—such as the surface of the lips,—it may give rise to the sensation of tickling; this sensation is produced, for example, by bringing a vibrating tuning-fork very close to the lips; it is also very readily excited in the tongue. It might be imagined that the sensation of tickling when arising from other causes—such as the slight contact of another body, and the sensation of sensual pleasure so nearly allied to it, are both dependent on vibrations of the nervous principle itself with a determinate rapidity within the nerves. The sensation of tickling, or the allied pleasurable sensations, may be produced in all parts endowed with common sensibility; but they are experienced with greatest intensity in the generative organs; less strongly in the female breast, in the lips, in the skin generally, and in the muscles.

The sensation of pain seems to depend on the violence with which the nerves of touch are irritated.

The feelings of warmth and cold are most frequently caused by changes produced in the condition of the organised tissues by the imponderable physical agent, caloric; but they are frequently present when no variation of temperature can be detected by the thermometer, being then produced by some internal change in the condition of the nerves. Moreover, the sudden sensation of very great cold, and that of burning heat, appear to be very similar.

In comparing the temperature of different media by means of the sense of feeling, the degree of capability of the media for conducting

ic must be taken into consideration. The same heat acts with
ι greater intensity upon our skin, and produces the sensation of
ι greater warmth, when the medium by which it is communicated
r sense is water, than when it is air. Cold water also feels much
r to us than air of the same temperature, because cold water con-
ı away the caloric of our body more rapidly.

ciprocal influence of the mind and the sense of touch.—When
ctivity of the sensorium is directed to a sensation, it is perceived;
ȝ, if the mind does not thus co-operate, the organic conditions for
ıensation may be fulfilled, but it remains unperceived. The dis-
ıess and intensity of a sensation in the nerves of touch, or common
bility, depends on the mind's co-operating for its perception. A
ful sensation becomes more intolerable the more the attention is
ted to it. A sensation in itself inconsiderable, as an itching in a
small spot of the skin, is thus rendered very troublesome and en-
ıg. When a person speaking to us spirts particles of saliva in our
, the idea attached to the saliva causes the sensation it produces to
ıuch increased in tensity and duration.

the co-operation of the mind, and the application of experience previously
d, we attain the faculty of referring sensations at one time to our own body, and
ther to external objects. Strictly speaking, we can feel only the present condi-
of our nerves, whether this condition be excited by internal or external causes.
ı we apply our hand to an external object, we do not feel the object itself, but
the hand which touches it; the mind, however, having already a conception of
cternal body, refers the sensation to it, and we say that we feel it. We have ex-
ed, at page 716, how the idea of external objects, as distinguished from our
body, is first obtained. The ideas which we obtain of different objects by the
have their source in the knowledge of the natural relation of the different parts
r body which is implanted in our sensorium; a faculty which is rendered more
and accurate by the exercise of the sense of touch, and in the adult attains such
ree of development, that, when our limbs are out of their natural position, if our
tion is not directed to this circumstance, we deduce from sensations excited in
the same ideas that we should do had they their natural relation to each other.
e, in the experiment, mentioned by Aristotle, of rolling a globular body between
ingers of one hand which are crossed over each other, the sensation obtained is
of two convex surfaces opposed to each, and apparently belonging to two separate
es.

sensation in a part endowed with touch appears to the sensorium to be, *cæteris*
us, more intense when it is excited in a large extent of surface than when it is
ned to a small space. The temperature of water, into which he dipped his whole
, appeared to Professor Weber to be warmer than water of really higher tempera-
in which he had immersed only one finger of the other hand. Similar observa-
may be made by persons bathing in warm or cold water.

every sensation is attended with an idea, and leaves behind it an idea in the
which can be reproduced at will, we are enabled to compare the idea of a past
ation with another sensation really present. Thus we can compare the weight of
body with another which we have previously felt, of which the idea is retained in
mind. Professor E. H. Weber was, indeed, able to distinguish in this manner
een temperatures experienced one after the other better than between temperatures
hich the two hands were simultaneously subjected. This power of comparing
ent with past sensations diminishes, however, in proportion to the time which has
sed between them.

ensations connected with muscular motion.—The muscles are
owed with a certain degree of sensibility, and, in spasmodic affec-
s of their nerves, become the seat of intense sensations. These sen-

sations are not, however, always proportionate to the degree of the muscular contraction; which renders it probable that the motion and sensation of the muscles are not due to the same nervous fibres. Thus, for example, the sensation of cramp in the muscles of the calf may be very severe, though the extent of muscular motion attending it is very slight. The same circumstance is sometimes observed in cramp of the digastric muscle of the lower jaw, which, when there is a disposition to repeated yawning, occasionally follows a violent movement of that kind: the pain then felt in the anterior belly of the digastric muscle is often extremely severe, though the movement of yawning has ceased, and the spasmodic action of the muscles has much diminished.

The sensation which informs us of the contraction of muscles enables us to estimate the degree of force exerted in resisting pressure or in raising weights. The perception of weight is more accurate than that of mere pressure, according to Professor Weber, who states that a difference between two weights may be detected when one is only one-twentieth or one-fifteenth less than the other. It is not the absolute, but the relative amount of the difference of weight which we have thus the faculty of perceiving.

It is not, however, certain that our idea of the amount of muscular force used is derived solely from sensation in the muscles. We have the power of estimating very accurately beforehand, and of regulating, the amount of nervous influence which it is necessary to emit from the brain for the production of a certain degree of movement. When we raise a vessel, with the contents of which we are not acquainted, the force we employ is determined by the idea we have conceived of its weight. If it should happen to contain some very heavy substance, as quicksilver, we shall probably let it fall; the amount of muscular action, or of nervous energy, which we had exerted, being insufficient. The same thing occurs sometimes to a person descending stairs in the dark; he makes the movement for the descent of a step which does not exist. It is possible that in the same way the idea of weight and pressure in raising bodies, or in resisting forces, may in part arise from a consciousness of the amount of nervous energy transmitted from the brain, rather than from a sensation in the muscles themselves. The mental conviction of the inability longer to support a weight must also be distinguished from the actual sensation of fatigue in the muscles.

So, with regard to the ideas derived from sensations of touch combined with movements, it is doubtful how far the consciousness of the extent of muscular movement is obtained from sensations in the muscles themselves. The sensation of movement attending the motions of the hand is very slight; and persons who do not know that the action of particular muscles is necessary for the production of given movements do not suspect that the movement of the fingers, for example, depends on an action in the forearm. The mind has, nevertheless, a very definite knowledge of the changes of position produced by movements; and it is on this that the ideas which it conceives of the extension and form of a body are in great measure founded. The sensorium may possibly derive this knowledge, independently of sensations in the muscles, from the consciousness of the groups of nervous fibres to which it directs the current of nervous energy. The accuracy with which the muscular movements are regulated and proportioned to their object, or the manifestation of the muscular sense, is most remarkable in all those movements by which the equilibrium of our own body, or of other bodies supported by us, when the base of support is small, is maintained; and

**ı the preservation of our balance during voluntary and involuntary movements of
hole body.**

uch, in its more limited sense, or the act of examining a body by
uch, consists merely in a voluntary employment of this sense com-
l with movement, and stands in the same relation to the sense of
ı or common sensibility, generally, as the act of seeking, following,
camining odours does to the sense of smell. Every sensitive part
ɜ body which can, by means of movement, be brought into different
ons of contact with external bodies, is an organ of "touch." No
part, consequently, has exclusively this function. The hand cer-
y is best adapted for it by reason of its peculiarities of structure,—
ly, its capability of pronation and supination, which enables it, by
novement of rotation, to examine the whole circumference of a
; the power of opposing the thumb to the rest of the hand, and the
ve mobility of the fingers. Other conditions for the exercise of the
of touch in great perfection are, great sensibility of the part, and
tinct perception of impressions on separate points of the sentient
ce. The regular grooving of the skin of the palm, with the ar-
ɜment of the papillæ in regular series, must increase the delicacy of
ı, inasmuch as the inequalities of the skin will more readily detect
nequalities of the bodies touched, and are better adapted for re-
ng distinct impressions from them.

forming a conception of the figure and extent of a surface, the
l multiplies the size of the hand or fingers used in the inquiry by
ıumber of times which it is contained in the surface traversed; and,
ɜpeating this process with regard to the different dimensions of a
body, acquires a notion of its cubical extent.

**_sations left after impressions;—modification of sensations by contrast._—The after-
tions left by impressions on nerves of common sensibility or touch are very vivid
urable. As long as the condition into which the stimulus has thrown the organ
es, the sensation also remains, though the exciting cause should have long
d to act. Both painful and pleasurable sensations afford many examples of this**

**e law of contrast, which we have shown to modify the sensations of vision,
ils here also. After the body has been exposed to a warm atmosphere, a degree
nperature very little lower, which would under other circumstances be warm,
ces the sensation of cold; a sudden change to the extent of a few degrees from
mer temperature, which has been of long duration, will produce the sensation
treme cold. Hence the facility with which catarrhs are contracted even in the
est climates. Heat and cold are relative terms. A particular state of the sen-
organ causes what would otherwise be warmth to appear cold. A diminution in
ıtensity of a long-continued pain gives pleasure, even though the degree of pain
emains would in the healthy state have seemed intolerable.**

ɜnsations dependent on internal causes are in no sense more fre-
ıt than in the sense of touch. All the sensations of pleasure and
, of heat and cold, of lightness and weight, of fatigue, &c. may be
luced by internal causes. Neuralgic pains, the sensation of rigor,
ıication, or the creeping of ants, and the states of the sexual organs
ırring during sleep, afford striking examples of subjective sensa-
ɜ. The increased force of the current of blood synchronous with
heart's contraction excites sensations in almost all the organs of
e; in the retina the periodic appearance of a luminous spectrum, in

the ear a periodic buzzing sound, in the nerves of touch a feeling of pulsation. There are mechanical causes for this sensation of pulsation, but it may be induced by a particular condition of the nerves; thus, it is often experienced in parts to which the blood is not sent with increased force.

The mind also has a remarkable power of exciting sensations in the nerves of common sensibility; just as the thought of the nauseous excites sometimes the sensation of nausea, so the idea of pain gives rise to the actual sensation of pain in a part predisposed to it. The thought of anything horrid excites the sensation of shuddering; the feelings of eager expectation, of pathetic emotion, of enthusiasm, excite in some persons a sensation of "concentration" at the top of the head, and of cold trickling through the body; fright causes sensations to be felt in many parts of the body; and even the thought of tickling excites that sensation in individuals very susceptible of it, when they are threatened with it by the movements of another person.

These sensations from internal causes are most frequent in persons of excitable nervous systems, such as the hypochondriacal and the hysterical, of whom it is usual to say that their pains are imaginary. If by this is meant that their pains exist in their imagination merely, it is certainly quite incorrect. Pain is never imaginary in this sense; but is as truly pain when arising from internal as when from external causes; the idea of pain only can be unattended with sensation, but of the mere idea no one will complain. Still, it is quite certain that the imagination can render pain that already exists more intense, and can excite it when there is a disposition to it.

The sympathies of the sense of touch with the other senses, and with muscular movements, are dependent on reflex nervous action; they have been discussed in the Chapter on Nervous Reflexions in the Book on the Physiology of the Nerves, where the sympathy between the secretions and sensitive impressions has also been considered.

BOOK VII.

OF THE MIND.

SECTION I.

OF THE NATURE OF THE MIND GENERALLY CONSIDERED.

CHAPTER I.

Of the relation of the mind to organisation and matter.

In the introductory portion of this work, which treated of general physiology, a comparison was drawn between an independent organised body or organism, and a piece of mechanism, the component parts of which are combined for the fulfilment of a determinate purpose, and depend for their individual action on the harmony of the whole. In this comparison we met with more points of dissimilarity than of resemblance. The organism and the piece of artificial mechanism resemble each other in the well-adapted combination of their several parts for the production of a general result; but the organic body is distinguished by the power of reproducing the mechanism of its own organs, in the form of germ, and of thus propagating itself. Again, not merely does the action of organic bodies depend on the harmony of their component organs, but this harmony itself is an action of the organism; while the cause to which each part of the organised system owes its state and properties resides not in itself, but in the cause which produces and maintains the whole. A piece of mechanism is formed in accordance with an idea held in view by the artificer, this idea being the purpose for which it is intended. An "idea" also regulates the structure of every organism, and of each of its component organs. In the former case, however, the ruling idea exists external to the artificial mechanism, namely, in the mind of the artificer; while the idea, which is the cause of the harmony of organic bodies, is in action in the organism itself, exerting in it a formative power unconsciously, and in obedience to determinate laws.

The cause which produces an organism being constrained to work out a predetermined plan, or pre-existent idea, necessarily maintains the form and endowments of one organism distinct from those of another, which is constructed according to a different idea. But, although this is the case, yet the different organic forms are connected by a more general principle of construction, which arranges them in classes, orders, families, genera, and species. The genus exists only in the different species which are quite independent of each other, and not as a distinct organism producing these species. Everywhere in the animal, as well as in the vegetable kingdom, we see manifested a perfect unity in the general plan, together with all logical modifications in the realisation of it: yet each of the various species which constitute a genus, cannot depart from its own specific type of structure and mode of action; so that the species ceases to exist as soon as all living individuals belonging to it and their germs have perished. Except in this sense, the species is immortal; since the vital force or principle which creates and maintains its organisation is successively imparted by the perishing, parent organisms, to the new beings which they produce.

The action of the vital principle which forms organic beings in conformity with determinate ideas, is known to us only by its effects *in* organic beings. If organic forms were produced spontaneously and independently of organisms already existing, we should have the phenomenon of a vital force operating in conformity with determinate ideas, elsewhere than in living organic beings. But the doctrine of the *generatio æquivoca* is constantly losing ground before the advances of strict investigation, and preserves merely the form of an hypothesis alike destitute of proof and incapable of demonstration.

It is in no way probable that the vital principle which produces the definite compound structure of an organism is itself a compound of distinct parts; and the same may be said of the sentient mental principle of animals. That which owes its integrity to its compound structure, must be rendered imperfect by division; but the organising principle of a plant or animal may be divided at the same time with the plant or animal in which it resides, and yet retain all its organising power. Thus the parts of a divided polype or planaria become, or are from the moment of their division, independent organic beings endowed with the power of producing the proper organisation of their species. So it is likewise with the sentient and thinking principle of animals; if indeed that principle is distinct from the vital principle. It cannot be a compound of different parts; for if it were, the division of an animal would necessarily destroy its integrity; and we know that an animal may be divided, and yet the mental principle in each portion remain perfect, manifesting sensation, volition, and desires. Whatever is true with regard to the mental principle of other animals, may be predicated of the mind of man; for everything which feels and moves voluntarily in accordance with its desires, is endowed with a mind. Such, indeed, was the remark of Aristotle, who, in his Essay on the Mind, says: "As soon as they feel, they must have thoughts and desires; for where there is sensation, there must be pain and pleasure; and where these exist, desires must exist likewise."

The vital principle and the mind or mental principle of animals resemble each other, therefore, in this respect: they exist throughout the mass of the organism which they animate; but, unlike it, are not composed of separate parts, and when divided together with the organism, do not suffer any diminution or change of their powers.

In a former part of this work, it has been proved that the vital principle has not its special seat in any other organ. The facts adduced in support of this position were the following:—First, the presence and activity of the vital principle in the germ before any organs are developed, and in anencephalous and acephalous monsters; secondly, the persistence of life in separated fragments of animals and plants, and the development of these fragments into perfect organisms; and, lastly, the phenomenon of the spontaneous organisation of the germ of the higher animals and man after its separation from the parent system. The separation of the germ from the parent is an instance of true division of an organism; the part separated in this case merely differing from the sprout cut from a plant, or the fragment of a divided animal in its possessing only the organising power, but not the already organised structure. The same force is in action in both cases. The circumstance of the stimulus to organisation being afforded to the germ by fructification, and the existence of distinct male and female sexes, are not valid objections to this proposition; since the influence of a fructifying matter is not necessary for the preservation of life in parts already organised when they are separated from the parent system; and even the dualism of the sexes may be reduced to a mere dualism of the sexual organs in one individual, as we see exemplified in plants and hermaphrodite animals, some of which latter are capable of self-impregnation.

It was also shown at the same time that the mental principle, or cause of the mental phenomena, viz. the conception of ideas, thought, &c. cannot be confined to the brain; but that it exists, though in a latent state, in every part of the organism. In proof of this was adduced the manifestation of mind, by sensations, volition, and desires, in new animals, developed from the germ and semen, from the buds of animals propagating by germination, or from the separated portions of those which divide spontaneously, as soon as the organs necessary for mental action are formed.

At the same time, however, a difference between the vital and the mental principle was pointed out in the dependence of the latter for its manifestation, as a conscious mind, on one organ—the brain. The mental principle exists only in a potential state in the germ, and is totally unable to manifest itself by perception, will, ideas, or thought, until the whole organisation of the brain is perfected by the plastic vital force.

The development of the germ is dependent on certain external conditions. The vital principle resident in it is unable to effect the organisation of its component matter until this matter is exposed to certain external influences, such as warmth and air. Without these aids the germ cannot assimilate the surrounding nutriment, owing to the unfitness of the latter to combine with the substance of the germ, so as to preserve its necessary chemical properties and composition. The vital principle, therefore, may itself exist in a latent or merely potential state in the germ, just as the mental principle has that condition in all parts of the fully developed organism except the brain. From these latter remarks, we may clearly infer the points of dissimilarity, as well as those of agreement, between the vital principle and the sentient mental principle. Both are simple, not composed of dissimilar parts, and therefore are divisible, together with the organic substance which they animate; and both are capable of existing in a latent state. But the vital principle requires for the manifestation of its organising powers only the chemical co-operation of certain external influences; while for the action of the conscious mind the presence of matter already organised with the structure of the brain is essential.

The germ and young animal are not distinguished from the fully developed organism merely by the imperfection of their organisation, and the smaller size of those organs which are developed in the young animal. A more essential difference between the germ and the organism in which the whole structure is perfected, and which is capable of generation and of producing offspring, consists in the latter being a multiple of the germ. Hence only can we explain the fact that a part of the fully organised or "multiple" animal may separate itself and become a new animal, while the rest of the parent organism loses nothing of its power of further organisation.

The development of the multiples of the germ by the process of growth will, in the Section on Generation, be demonstrated to take place both in plants and in the Coralline Polypifera, Naides, Vorticellinæ Polygastrica, Planariæ, and Hydræ. Here we shall see the multiplication of the original organism manifested by the formation of buds, and by spontaneous division, while the multiple character of some others will be rendered evident by the persistence of life in portions separated by artificial division.

The portions of a divided Hydra have not at first the whole structure of a perfect animal, but they soon develope that structure within themselves. This fact shows us that the multiplication of an individual does not necessarily consist in the increase of analogous forms with analogous endowments, but may take place only virtually, in such a way that the forms produced are unlike the original, though their virtual endowments are the same. And thus we are led to understand the process subsisting in the higher animals, which, though capable neither of propagation by spontaneous division, nor of living after artificial division, yet are virtually a multiple of the germ from which they were developed. Here a part of the multiple animal can separate from the rest in a state capable of continued life and development only when it has become isolated in the form of an undeveloped germ. Now, in all the modes of propagation to which we have alluded, those of spontaneous or artificial division, germination, and sexual generation, both the vital principle and the mental principle, as we have before shown, undergo division.

The questions next present themselves, how is it possible for the growth of an organic being to cause a multiplication of its organising force? and how is the divisibility of the mental principle acquired at the same time, to be explained or understood? Is it a peculiarity belonging to the nature of the vital principle, and also of the mental principle, as a potential essence, that their extension through a large mass of matter, and their subdivision, is incapable of diminishing their intensity? or does the mere assimilation of new matter by a growing organism give rise to an increase of those principles, in consequence of their being contained in the nutritive matter itself in a latent state, though they are incapable of manifesting themselves until the matter is assimilated by an organic body?

The supposition last proposed necessarily involves a second, namely, that the principles of life and mind exist in a latent state in all matter; for although animals are capable of assimilating merely vegetable matters, plants, on the other hand, increase their substance from inorganic materials: indeed, unless there were such a new formation of organic matter from the inorganic elements, organic beings must at length perish, owing to the great destruction of organic substances by putrefaction and combustion.(*a*)

CHAPTER II.

PHENOMENA RESULTING FROM THE ACTION OF THE MIND AND BODY ON EACH OTHER.

So soon as the structure of the brain is developed, and the action of the senses commences, ideas or mental actions also arise; and, just as light may be developed in an inorganic body, by a mechanical shock and change in its physical condition, in the same way changes in the action of the mind may be produced by changes impressed on the

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(*a*) The author now begins a course of avowedly hypothetical speculations on "*Cosmological Systems*," which, however agreeable to my own tastes, are not, in their present connection, adapted to benefit the student of Physiology, and they are, therefore, omitted here.

organisation of the brain or on the matter which enters into its structure. On the other hand the operations of the mind, with which the organisation of the brain keeps, as it were, equal pace, induce changes in the structure and component matter of that organ, and of all other parts of the body which are under its influence. The ideas and thoughts are not themselves composed of parts, but they are developed in matter which has organisation and parts, and the distinctness of the conceptions is entirely dependent on the condition of this divisible matter.

Hence we may infer that, whatever changes the mind produces in the organism generally, are effected through the medium of the brain—the organ in which alone the mental force, elsewhere latent, is manifest, and from which its influence radiates, as from a centre, to all other parts of the body. Every organ, also, by virtue of its power of acting on the brain itself through the medium of its nerves and of the blood circulating through the whole organism, must have an influence upon the ideas and upon the power of mental conception. This influence may be either exciting or depressing, so that the power of the mind to conceive ideas may be either increased or impeded. The impressions communicated from different organs of the body to the brain can, of course, produce no other distinct ideas than those of the sensations, and the peculiar import of these sensations. But since local changes of particular organs may produce the sensations of pleasure or suffering, or of the tendency of the organ to its specific function, and may thereby excite the ideas of the expansion and restriction of self and of desire, which are associated with those sensations, it is evident that the disposition to a state of emotion may be kept up by the state of other organs than the brain.

1. *Influence of states of the body upon the intellect and emotions.* —The excitement of certain organic states of the brain, by the bright scarlet aërated blood, is a necessary condition for the action of the mind. Hence the abstraction of blood in large quantity produces syncope and loss of consciousness. Even the quality of the blood, however, exerts an influence on the intellectual operations. The most common instance of an influence exerted on the mental faculties by a cause of this kind, is afforded in the effects of digestion. The digestion of food introduces a quantity of imperfectly assimilated matter into the circulation. Until this new material has undergone the necessary changes, and while certain matters, altogether unfit for nutrition, are mingled with it, it is not adapted to excite those states of the brain which are necessary for the proper manifestation of mind, and as it is conveyed to that organ by the circulating blood, it produces an injurious change in it, and impedes or disturbs the mental functions. Hence the indisposition to mental labour experienced by some persons after meals. This disturbance of the intellectual operations is still more evident, as the result of the material changes produced by the *alterantia nervina* (spirituous liquids and narcotics). Some "secreta" and "excreta," as bile and urea, are equally unfitted for producing the natural organic states of the brain. The former substance being absorbed into the blood, produces not only indisposition to the exercise of the intellect, and diminution of its power, but also depression of spirits, by disturbing those organic conditions of the brain which influence the emotionary feelings.

A second source of causes disturbing the action of the mind, through the medium of changes produced in the brain, is found in those states of other organs, which act on the brain through the medium of the nerves. Every part of the body, which stands in the relation of active sympathy with the central organs of the nervous system, is capable, when itself in a state of strong excitement, of exciting strongly the brain, and thereby the mind also; or, when in a state of depressed action, of diminishing the activity of their functions: hence, delirium and stupor are effects of those states in some parts of the body. The emotions of the mind are also affected in this way; long continued disturbance, or arrest of the functions of important organs, giving origin to a fretful, dejected state of feelings, which is nothing else than a state of impeded strivings of the mind. Those organs which are engaged in effecting chemical changes in the organic matters of the fluids, such as the internal viscera, act on the mind in two ways, for they depress the power of action of the central organs, not only through the medium of nervous connection, but also by changes impressed on the blood. The effect of the latter mode of action varies in degree, according to the kind of change produced in the blood by the viscera. Hence it is that the abdominal viscera are distinguished above all others, by the influence of their chronic maladies, in giving rise to a long continued depression of the strivings of the mind.*

There are organs of the body, particular states of which excite passions connected with their functions; such are the sexual organs and the stomach. These organs excite sensations of particular kinds, and ideas of things fitted to restore the integrity of self, which is felt to be in an impaired or restricted state. On the other hand, the idea of that which would restore the integrity of self, or increase its power, determines currents of nervous energy towards the particular organ. For, as we have already seen, this idea of a state which can be realised by a particular organ, excites a current of nervous influence towards that organ, whether it be a muscle or a gland. In this way it is the disposition to the passion of love excited by particular states of the sexual organs or of the spinal cord, the medium of nervous communication between those organs and the brain. "If both the sexual organs and the spinal cord have a certain degree of tension, the mind is thrown into such a state, as causes corresponding ideas to arise. The active state of the organs excites the idea, and the idea may produce that condition of the organs; but, unless the organs are in a state of potency, the ideas to which they are related remain cold, and do not influence the organic conditions and actions. Particular kinds of food also, have an influence on particular states of passion by their action on the corresponding organs of the body. Lastly, the state of the whole nervous system, and the degree of its excitability, and of the facility with which impressions are propagated through it, exert an influence on the emotions. For those persons, in whom any excitement spreads very rapidly through the nerves, and still more rapidly leaves behind it a state of exhaustion, are more liable than others to all emotions in which the feeling of self undergoes a violent and sudden change and depression, such as fear, anxiety, terror, &c. But they whose nervous system is differently constituted, and is not exhausted or depressed in consequence of previous excitement, experience from sudden excitement only the emotion of courage, and manifest persevering efforts to maintain or extend the power of self. Animals display different tendencies of their organic states and functions, according as they are by nature timid or courageous. In man, these dispositions to particular emotions vary with the organic state of the body: a person, gifted with great coolness and presence of mind, may be so altered, temporarily, by a particular state of his nervous system, as to be startled like a naturally timid person, by any sudden occurrence; whilst abundant food and a glass of wine will give courage to the faint-hearted.

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* See page 615, where the seat of the passions is shown not to be in those viscera.

The operations of the mind are affected in the greatest degree by changes in the organic conditions of the brain itself, such as inflammation, malformation, and pressure. Every state of irritation of the brain causes delirium; everything which impedes the organic actions in the brain produces syncope, stupor, or complete coma. Hence the most various structural changes in the brain, as tubercles, pus, extravasated blood, and water, give rise to nearly the same symptoms. Pressure of blood, still within its vessels, also produces insensibility. And the effects of inanition are, in this respect, exactly the same as those of pressure.

Structural changes in the brain itself are much more prone to disturb the intellectual faculties than to excite or depress the passions. A depressing passion cannot be intense without the concurrence of ideas, in a certain degree of intensity, which shall keep up the passion; but when the organic actions of the brain are impeded, this intensity of ideas is impossible: hence, even in these cases, the principal effect of structural change of the brain, appears to be impairment of the intellectual faculties. The organic conditions, on which the integrity of the intellectual faculties depends, exist, without doubt, in the brain itself; but the elements which maintain the emotions or strivings of self, in all parts of the organism.

2. *Influence of ideas and emotions of the mind upon the body.*

The influence of ideas upon the body gives rise to a very great variety of phenomena, which border on the marvellous. It may be stated as a general fact, that any state of the body, which is conceived to be approaching, and which is expected with perfect confidence and certainly of its occurrence, will be very prone to ensue, as the mere result of that idea, if it do not lie without the bounds of possibility. The case mentioned by Pictet, in his observations on nitrous oxide, may be adduced as an illustration of such phenomena. A young lady, Miss B., wished to inspire this intoxicating gas; but in order to test the power of the imagination, common atmospheric air was given to her, instead of the nitrous oxyde. She had scarcely taken two or three inspirations of it, when she fell into a state of syncope, which she had never suffered previously; she soon recovered.* The influence of the ideas, when they are combined with a state of emotion, generally extends in all directions, affecting the senses, motions, and secretions. But even simple ideas, unattended with a disturbed state of the passions, produce most marked organic effects in the body. This we shall now proceed to demonstrate.

a. Influence of the mind upon the senses. Phantasms.—Phantasms or hallucinations are perceptions of sensations in the organs of the senses, dependent on internal causes, and not excited by external objects. These phenomena have been repeatedly confounded with mere ideas, and have been regarded as ideas which are not distinguished from realities. But the very belief in their reality is owing to their being seated in the senses, and having all the truthsomeness of real sensations; moreover, this belief in their reality is not an essential character of such phenomena. It would be an error of the understanding to believe in the reality of mere ideas. But these phantasms may present themselves with all the distinctness and force of a real sensation, with colour or with sound, and yet not to be mistaken for real impressions from without. The false views entertained respecting these phenomena, have arisen from the hallucinations of the insane having been principally the subject of observation: hence I avoid the use of the term hallucination. The name of visions is a more correct expression for the states now under consideration, when they affect the sense of sight. For they are really affections of that sense, and have their seat as truly in its apparatus as any visual perceptions from external impressions. Even the sensations of the sense of sight, excited from without, afford us the opportunity of observing the influence of ideas on the state of the retina; since certain parts of images acquire an extreme distinctness, from being made the subject of more particular conception by the mind, or, in ordinary language, from the attention being particularly directed to them.

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* The case is given in the German translation of Sir H. Davy's Researches on Nitrous Oxyde (Untersuchungen über das oxydirte Stickgas, 2 Bd. Lemgo. 1814, p. 326).

Without actual sensations, we are accustomed to conceive the presence of outlines, and, consequently, of forms, in the dark field which appears before the closed eyes. This seems to result from a few particles or points of the retina becoming the subject of conceptions. No illuminated and coloured image is perceived in this case. For such a result, it would be necessary that the particular points of the retina should be conceived as being, not in the state of rest, but in that of action, on which the appearance of light and colour depends. This production of colourless figures in the field of vision, by an action of the mind, is, however, sometimes so perfect, that outlines of objects on which the eyes have been long fixed, return with great distinctness. For example, the forms of structures which have been attentively examined with the microscope, suddenly present themselves to our vision, even though many hours have elapsed since they were actually seen. But not merely outlines of objects which have been presented to our sense of vision, are reproduced; new configurations also appear at times, when external impressions are excluded. This happens frequently to children of active imagination, when they are placed in the dark: faces and terrific forms seem to present themselves to them in outline, and devoid of colour and light. All these phenomena appear to result from some kind of reciprocal action, which takes place between the sensorium and the retina.

The subjective images of which we are speaking have sometimes, however, both colour and light; different particles of the retina, of the optic nerve, and of its prolongations to the brain, being conceived as existing in special states of action. This happens rarely in the state of health, but frequently in disease. These are the true phantasms which may occur to the sense of hearing and other senses, as well as to that of vision. The process by which "phantasms" are produced, is the reverse of that to which the vision of actual external objects is due. In the latter case particles of the retina thrown into an active state by external impressions, are conceived in that condition by the sensorium; in the former case, the idea in the sensorium excites the active state of corresponding particles of the retina or optic nerve. The action of the material organ of vision, which has extension in space, upon the mind, so as to produce the idea of an object having extension, form, and relation of parts, and the action of such an idea upon the organ of vision so as to produce a corresponding sensation, are both equally wonderful; and hence, the spectral phenomena or visions are not more extraordnary than the ordinary function of sight. The following are the states of the body in which the above phenomena are observed:—

a. Immediately before sleep, at the time of waking, and when half awake. Who has not observed the vivid images which present themselves to the eye before sleep; the light which sometimes appears to the closed eyes at that time; the forms sometimes brightly illuminated, which suddenly present themselves, and quickly change;

or the sudden sound, as if one called loudly in our ears, which, in that state, is heard without any external cause?[*] A close attention to one's own condition at the time specified, is quite convincing as to the phenomena in question being real sensations, and not merely ideas. Any one who can watch the changes which take place in himself, at the time when sleep is coming on, will sometimes be able to perceive the images distinctly in the eyes. On waking, too, in a dark room, it sometimes happens that images of landscapes and similar objects still float before the eyes. Aristotle, (in his *Essay on Dreams*, chap. iii.) Spinoza, (*Opera Posthuma*, epist. 30,) and still more recently, Gruithuisen, have made this observation. I have, myself, also very frequently seen these phantasms, but am now less liable to them than formerly. It has become my custom, when I perceive such images, immediately to open my eyes and direct them upon the wall or surrounding bodies. The images are then still visible, but quickly fade. They are seen whichever way the head is turned, but I have not observed that they moved with the eyes. The answers to the inquiries which I make every year, of the students attending my lectures, as to whether they have experienced anything of the kind, have convinced me that it is a phenomenon known to comparatively few persons. For among a hundred students, two or three only, and sometimes only one, have observed it. This rarity of the phenomenon is, however, more apparent than real. I am satisfied that many persons would perceive these spectres, if they learned to observe their sensations at the proper times. There are, however, undoubtedly many individuals to whom they never appear, and in my own case they now sometimes fail to show themselves for several months at a time, although, in my youth, they occurred frequently. Jean Paul recommended the watching of the phantasms which appear to the closed eyes, as a means of inducing sleep.

b. The facts already mentioned prove that the images seen in dreams,—not the mere ideas of things conceived in dreams,—are phenomena of the same kind as the phantasms. For the images which remain before the eyes when we awake, are identical with the objects perceived in our dreams.[†] Even the blind sometimes see in their dreams images of luminous objects.[‡]

The phenomena hitherto described, may occur to any person in the state of health.

c. The diseases in which the occurrence of phantasms is frequent, are fever, nervous irritation of the brain, phrenitis (in which disease they remain for some time during convalescence), narcotism, insanity, and epilepsy.[§] The well known bookseller of Berlin, Nicolai, when suffering from intermittent fever, saw coloured pictures of landscapes, trees, and rocks, of half the natural size, which appeared to him even before the cold stage set in, and resembled frame paintings. If he kept his eyes closed, they underwent constant changes; some figures disappeared, while new ones showed themselves. As soon as he opened his eyes the whole vanished. Inflammation of the optic nerve is also attended with the perception of luminous phantasms. A very remarkable case was observed by Lincke, (*De fungo medullari oculi.* Lips. 1834,) in which the extirpation of an eye was followed by the appearance of luminous figures before the orbit, as long as the inflammation consequent on the operation endured. In another case, (*Berliner Monats-schrift*, 1800, p. 253,) a female, who was stone blind, complained of having luminous images with pale colours before her eyes. These cases prove that the presence of the retina is not a necessary condition for the production of such phenomena; but on the contrary, that the deeper seated parts of the essential organ of vision are alone required. It is an old and frequent observation, that pressure, exerted on the brain, in persons who have been trepanned, causes them to see flashes of light. Esquirol knew an insane person who saw visions, and in whom, after death, he found both optic nerves in a state of atrophy from the eye to the chiasma. (*Dict. de Scienc. Méd. Art. Hallucinations.*)

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[*] A detailed account of these phenomena is given in Moritz and Pockel's Magazin der Erfahrungsseelenkunde, 5 b. 2 p. 88; by Nasse, in his Zeitschrift für Anthropologie, 1825, 3. p. 166; and in J. Müller Ueber die Phantastischen Gesichts-erscheinungen. Coblenz. 1826, p. 20.

[†] See Goethe, Vorrede zur Farbenlehre; also the excellent remarks of Gruithuisen, in his Beiträge zur Physiognomie und Eautognosie, p. 236.

[‡] See J. Müller, op. cit., and Herman in Ammon's Monats-schrift, 1838.

For an account of phantasms seen in the state of narcotism, consult Sir H. Davy's [illegible] on Nitrous Oxyde. Richerz, in Muratori, über die Einbildungskraft. 2, th. Leipz.

In cases of insanity, phrenitis, cerebral irritation and narcotism, the phantasms are seen even when the eyes are open, and combine with the impressions produced on the sense of vision by real objects.

Simple cerebral irritation, in persons who are not insane, may give rise to what is called the seeing of visions. According to the tendencies of the mind, the phantasms seen under these circumstances will be of a religious, consolatory, and benignant character, or fearful forms of living or dead persons, as in the case of the so called "second sight" of northern nations. The vision may be seen with the eyes open, the images from internal causes mingling themselves with those of real objects. In this case, it may happen that the images of external objects are seen through the phantasms as through a veil. In some instances persons see the forms of other individuals; in others, their own forms. According to the degree of mental culture of the subject of these visions, are they regarded as real, or as the result of a disordered state of the sensorium. In the former case the spectre-seer not only mistakes his own condition, but he is regarded erroneously, both by the superstitious and credulous multitude, and by the more skeptical persons, who think him a madman or visionary. When a person who is not insane sees spectres, and believes them to be real, his intellect must be imperfectly exercised.

We have instances of persons seeing spectres, and recognising their true nature, in the case related by Bonnet and in Nicolai. Bonnet (*Analytische Versuche über die Seelenkräfte. Bremen*, 1780. 2 Th. p. 59) knew a gentleman gifted with perfect health of body, with candour, good judgment, and memory, in whom, from time to time, when he neither had recently awoke nor was inclined to sleep, figures of birds, carriages, and buildings appeared, independently of all external cause, and moved before his eyes. Sometimes the carpet of his room seemed all at once to change its pattern. The spectral images, here, were as distinct as real objects. This gentleman, however, judged rightly as to the nature of the phenomenon, and corrected any first erroneous impressions.

Nicolai, whose case is so frequently quoted, was accustomed to be bled twice a year, and to have leeches applied two or three times annually for the relief of hæmorrhoids. During the latter part of the year 1790 both these measures had been omitted, and it was early in 1791 that the spectral illusions first appeared to him. After a violent quarrel and agitation of mind, he suddenly perceived at a short distance in front of him, a form like that of a deceased person. Later in the same day there appeared several other walking figures, which continued to appear for some days. Nicolai could in no way regulate the appearance of these phantasms by his will; he could not even determine the appearance of one person rather than another. The figures were for the most part those of strangers. They appeared both by day and night, and presented the different colours of the flesh and dresses, though the colours were paler than in natural objects. After the lapse of four weeks, during all which time Nicolai continued to walk abroad, the phantasms began to talk. At the end of about two months leeches were applied to the anus, and on the very same day the phantasms began to fade and to move more slowly. At length they seemed to dissolve away, leaving fragments visible for a considerable time.* It is very rarely that the power is possessed of producing at will, in the form of phantasms, while the eyes are closed, images of the objects conceived as ideas in our minds. The cases of Cardanus, Goethe, and a few others mentioned in my essay already referred to, are instances of this power. Goethe in his tract "Zur Morphologie und Wissenschaft," says, "when I closed my eyes and depressed my head, I could cause the image of a flower to appear in the middle of the field of vision; this flower did not for a moment retain its first form, but unfolded itself, and developed from its interior new flowers, formed of coloured or sometimes green leaves. These were not natural flowers, but of fantastic forms, although symmetrical as the rosettes of sculptors. I was unable to fix any one form, but the development of new flowers continued as long as I desired it, without any variation in the rapidity of the changes. The same thing occurred when I figured to myself a variegated disk. The coloured figures upon it underwent constant changes, which extended progressively, from the centre towards the periphery, exactly like the changes in the modern kaleidoskope."

In the year 1828, I had the opportunity of conversing with Goethe upon this subject, in which we were both much interested. He knew that I frequently saw different figures in the field of vision, when I lay quietly down to sleep, with my eyes closed, but before sleep had actually come on; and he was very desirous of learning what forms these images took in my case. I explained to him that I had no voluntary power over either the production of these images or their changes of form, and that they never presented the slightest tendency to a symmetrical and vegetative development. Goethe, on the contrary, was able to give the type for the phantasm, and then the different variations ensued it, as it seemed, independently of the will, though with regularity and symmetry. This difference accorded well with the characters of our minds, of which the one had the creative power of the poet, while the other was engaged in the investigation of the actual phenomena of nature.†

b. Influence of ideas upon motions.—Ideas produce motions even more readily than they produce sensations. The following are the conditions in which such phenomena occur:—

1. The resolve to execute a particular motion sets in action the corresponding cerebral nervous fibres, and the motion is effected, if it be possible, through the medium of the cerebro-spinal system of nerves. (See account of the voluntary movements at page 673.)

2. The idea of a particular motion also determines a current of nervous action towards the necessary muscles, and gives rise to the motion independently of the will. In this way the movements of yawning, laughing, &c., are produced involuntarily, when another person is seen to yawn or laugh. (See page 672.)

3. Any sudden change in the ideas, though without emotion, and having reference to mere external objects, may excite involuntary motions; such as that of laughter. We have instances of a similar kind in

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* Berliner Monats-schrift, 1799, Mai. It is known only to a few persons, that Goethe, who had been offended with Nicolai, satisfied his revenge by caricaturing him as the Proctophantasmist, in the scene on the Blocksberg, in Faust.

† Compare Abercrombie's Inquiries concerning the Intellectul Powers, Edinb. 1830. On the phantasms of the sense of hearing, see my own work already referred to, p. 80, and Froriep's Notiz. B. x. p. 10.

the motions which occur when two ideas are suddenly conceived to contradict each other, or when the solution of a difficulty is conceived unexpectedly.

4. The idea of our own strength gives strength to our movements. A person who is confident of effecting anything by muscular efforts, will do it more easily than one not so confident in his own power. The idea that a change is certainly about to take place in the actions of the nervous system, may produce such a change in the nervous energy, that exertions hitherto impossible become possible. This is still more likely to be the case, if the individual is at the time in a state of mental emotion.

5. The passions or emotions themselves give rise to involuntary actions or relaxations of muscles, according as the state of passion is dependent on exciting or depressing ideas. The same passions occurring frequently induce a fixed expression of the features, and betray the characteristic temper of the mind, in the same way that each passion which occurs declares itself by its corresponding physiognomical motions. (See pages 672—674.)

c. Influence of ideas upon nutrition, growth, and secretion.—The phenomena dependent on the influence of ideas of the mind upon the processes of the body are very analogous to the foregoing. They may be arranged as follows:—

1. Excessive exercise of the mind diminishes the activity of the nutritive processes.

2. An idea having reference to a secretion causes a stream of nervous energy to be directed towards the secreting organ; and, if the mind is at the same time occupied by a passion or an emotion, the effect just mentioned is more marked. Thus, the saliva is secreted in greater abundance when the idea of food occurs to the mind; the secretion of milk is increased when the young are about the mother, and when the idea of them, rendered intense by emotion, occupies her mind; the conception of voluptuous ideas causes the semen to be secreted in larger quantity.

3. The idea that a structural defect will certainly be removed by a certain act increases the organic action of the part, and sometimes produces a cure. Hence, the cure of warts by what is called sympathy; *si fabula vera.*

4. The passions sometimes excite profuse secretions, such as a flow of tears, or perspiration, or diarrhœa; sometimes they repress the organic chemical processes by which the secretions are formed, so as to alter their quality. From the latter cause, the milk of a woman who is nursing becomes after a fit of passion indigestible and irritating to the child. Under certain circumstances, also, the passions cause the suppression or retention of secretions: thus the urine is watery, from the natural ingredients of that fluid not being eliminated, after a fright; and anger, grief, and other emotions give rise to jaundice, by causing the matter secreted to be re-absorbed into the capillary blood-vessels of the liver, instead of being carried out by the branches of the bile duct.

5. Predispositions to particular diseases of nutrition speedily manifest themselves by actual lesions under the influence of passions. Grief, and deep suffering, in a very short time develope phthisis, liver disease, and affections of the heart, when a predisposition to those maladies previously exists.

6. The culture of the mind by observation and varied attainments

ennobling influence on the corporeal form, and particularly on aments of the face. A comparison of the forms and features neral in the different classes of society leaves no doubt as to the this remark. The form which is acquired becomes hereditary. fluence is most manifest in the most exclusive ranks of society, seldom intermarry with other ranks, and in which the education children is carefully attended to. The only way in which we nceive the form of the features to be influenced by the culture mind is, that all excess of nutritive matter is removed from and their formation more strictly confined to the type of the m.

nental phenomena in compound and divided animals, and in animals united by abnormal concretion.

ompound animals.—Among the lower animals there are many which really t systems of numerous individuals, united by one common stem. Plants, , are aggregates of many concurrent individuals rather than simple organisms. leaf-buds of a plant are individuals which have all the same structure, have the f independent existence when separated artificially or spontaneously, and are of developing new systems of similar individuals. The vessels of each bud onged in the vascular layers of the common stem as far as the root, and thus resembles a fasciculus of distinct individual plants, which develope themt different points of its length.

ompound animals comprehend the compound Vorticellinæ, Polypifera, Entozoa, llusca, as well as all those animals which propagate by division, at the period eir separating parts are not wholly detached. Two distinct individuals of the nd animals are sometimes united by a common stem, of which they represent ches, and from which they are developed by the formation of buds; as in the the compound branched polypes. Sometimes they are united in a radiate , which is the form of the Botrylli; whilst in other cases many are connected nass, or, like the Infusoria, which propagate by longitudinal division, they are n a lateral series; or, again, like other Infusoria, and some Annelida,—which te by transverse division,—they are connected in a longitudinal chain. Most and all the compound animals, are to be regarded as families of individuals, ither are developed singly upon the common stem, as in the majority of in-, or are compound even in their embryonic condition, as in the case with the i, according to the observation of Sars. (*Froriep's Notizen*, 1837, No. 51.) In stances the different individuals composing the compound animal have certain nt organs in common. Thus, in the Sertulariæ, the canal of the stem communiith the digestive cavities of each single polype. In the Hydræ, it was observed mbley that the digestive cavity of the young polype at first formed part of that arent animal, and that the food passed from the one to the other. In the Nais, ring the development of several new individuals by division, the intestinal canal inued through the whole series, and the parent animal takes food for them all. e Annelida which undergo spontaneous division, the imperfectly formed new es, which are merely composed of a certain number of the segments of the animal, at one period evidently obey the sensorium seated in the cephalic porthe parent, and execute its desires and resolves. But, in proportion as their ion becomes more complete, and the parts which are to form the new animals independent, and acquire new centres of nervous action by development of ephalic portion, each of these new worms, also, becomes endowed with special d desires, which it manifests distinctly enough even before it is quite separated, attempts to detach itself from the body of the parent worm.

distinct polypes, which are united by a common stem in the compound Polypire independent individuals, endowed with an independent will and nervous . The irritation of a single polype causes the retraction of that one only, and all the polypes of the stem. The stem itself has no individuality; it has no , and is incapable of conceiving any object of desire. In it, however, resides the power of producing new individuals by the process of gemmation. In the persistent branched polypiferous animals the stem is not even capable of motion by the will of the individual polypes. Kaup, it is true, observed [illegible] by slight motions of a peculiar character in the stem of Veretillum, but these did not resemble voluntary motions. The Hydræ, while they are undergoing multiplication by gemmation, are compound systems of individuals, but these individuals after a time separate from each other, and the stem in them does not bear the same relation to the separate polypes as it does in the permanently compound Polypifera. The stem of the Hydra constitutes from the first the main part of the parent polype, and is subject to the cephalic portion of that individual; while, on the other hand, the young polypes manifest the influence of their will only as far as the point at which they are connected with the parent trunk, and at which their separation from it afterwards takes place.

b. Double monsters of the human species and of brutes.—Respecting the mode of formation of these double monsters, all that is essential has already been said. The following natural divisions include their various forms. The abundant examples contained in the Museum of Berlin may all be referred to one or other of the following general heads:—

I. The axis of the body in part double.

a. The upper part of the trunk double, while the lower part is single. *Axis superius duplex.* Of this form of double monster, in which the cephalic and spinal axis are bifid at the upper part, there are all degrees, from the monster with a double muzzle or double head, to that in which the whole upper part of the body, as low as the sacrum, or still lower, is double.

b. The lower part only of the trunk or axis of the body double. *Axis inferius duplex.* Of this form, also, there is every degree, even to that condition in which the entire trunk, and even the posterior part of the head, are double, and only the snout single.

II. *Axis duplex.* Two bodies with their axes distinct, united by identical parts with or without defect at that point of union.

a. Union without deficiency of parts; all parts of the two embryos being perfect. In this case each embro seems to be partially cleft. For example, in the head of one $a\!-\!\begin{matrix}b\\b\end{matrix}$, the two halves of the face, *b* and *b*, are separated from each other, the occiput, *a* remaining undivided; and, in the same way, the two halves of the face, β and β, in the head $\begin{matrix}\beta\\\beta\end{matrix}\!-\!\alpha$ of the other embryo, are separated, while the occiput, α, remains single. Hence there is this confusion, $a\!-\!\begin{matrix}b\beta\\b\beta\end{matrix}\!-\!\alpha$, of the parts of the united head; each face, *b*β, of the double head being composed of halves, which belong to two different embryos. The examination of the cranium and brain proves that this is the case.* The syncephalus, synthorax, syngaster, as well as the pygodidymus of Gurlt, when not combined with deficiency of parts, are varieties of this form of monstrosity. The syncephalus, without deficiency of parts, is the true Janus-monster. But there are cases of synthorax and syngaster, in which the condition of the thorax and abdomen is the same as that of the head in the Janus-monster.

b. Two embryos united by identical parts, with defect at the place of coalescence. Monstrosities of this kind are due to the same principle as the coalescence of corresponding organs of the two sides of the body in single monsters. The coalescence and loss of parts may be situated either at the side or at the front of the body. Such are the syncephalus aprosopus, in which the faces of both embryos are deficient, and the corresponding forms of the synthorax and syngaster. From the lateral syncephali there is a gradual transition to to the monsters with partially double axis.

c. Two bodies united by dissimilar parts.

III. *Implantatio.*—Two bodies united, but only one perfectly developed, while the other remains in a rudimentary state.

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* Compare J. Geoffroy St. Hilaire, Hist. des Anomalies, tom. iii. p. 110.

lantatio externa.—1. *Implantatio externa æqualis*, in which the parts of the t embryo are connected with corresponding parts of the perfect one; as, for where the posterior parts of the body of a diminutive fœtus hang to the he thorax of a fully formed child; or where a third foot, parasitic hand, or erary jaw is present. 2. *Implantatio externa inæqualis*, in which the perfect rfect fœtus are connected by dissimilar points.

lantatio interna; where one fœtus contains within it a second.

Parts of the body external to the axis, cleft so as to be double. netimes difficult to distinguish this form of monstrosity from the ng.*

nowledge respecting the mental phenomena of double monsters limited, the opportunity of observing them occurring very rarely, st of these monstrous fœtuses dying soon after birth. Some few tions, however, have been instituted upon the most important f monstrosities. In that form in which the upper part of the double, and the lower part single, it is found that the two heads each possess voluntary influence over the entire lower half of y, as might have been expected; but that the right head moves e right half of the body and the right lower extremity, while the d moves the left half of the trunk and left lower extremity. results have been obtained by observations instituted in the case . Christina.† Irritation of the right foot also was felt only by t head, and irritation of the left foot only by the left head. It ly when the middle line of the body was touched that it was felt heads. This form of monstrosity, therefore, would appear to ather from the fusion or coalescence of two embryos, with loss ruction of the intermediate parts, than from the partial division germ. In Rita and Christina the intestinal canal was double as the ileum, but thence downwards it was single. The desire of ting the bowels was almost always felt simultaneously by both. can, consequently, be no doubt that the single part of the intes- nal was produced by the coalescence of two intestinal tubes, of which a part of the walls was lost. (Consult *J. Geoff. St. e*, iii. p. 189.)

respect to the monsters in which the brain and cranial cavity are single, while zle or the trunk is double, I have myself had the opportunity of making a bservation upon the laws of their sensations and volition. It was in the case , of which the body and occiput were single but the anterior part of the head muzzle double, there being three eyes, of which the middle one resulted from n of the internal eyes of two faces. It is not many years since I saw this e; I was able to observe it only for a short period, and know nothing of its . As the creature was not my property, I was only interested in ascertaining vas affected by sensations. I touched, therefore, one of the mouths with a d was surprised to see the tongues of both mouths protruded simultaneously exactly the same manner. I cannot exactly recollect whether both tongues when protruded, or whether they both moved towards the same side; but I r inclined to think that the former was the case. It is much to be desired that rtunities of observing such cases should not be neglected. The simultaneous tation of one will in both the double parts of such monsters would accord better idea of their being produced by partial division of the germ, than with that being due to the coalescence of two germs.

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the anatomy of the double monsters, consult Barkow, Monstra animalium per anatomen indagata. Lips. 1828.

res, Recherches d'Anatomie Transcendante et Pathologique. Paris, 1832.

The cases of *implantation* are most frequently met with. The parts of the imperfectly developed embryo, when destitute of head, are generally void of sensibility, the perfect individual being conscious of no sensation from impressions made upon them. Such was the case in the body examined during life by Barkow. (*Med. Zeitung des Vereins für Heilkunde in Preussen*, ii. 206.), in which four well-formed extremities hung from the superior abdominal region. This monster is preserved in the Anatomical Museum of Berlin. The appended extremities receive no nerves from the larger trunk, but are nourished by its mammary arteries. (For a description of several similar cases, see J. Geoff. St. Hilaire. Op. cit.) Cases of this kind, however, have been observed in which irritation of the rudimentary remains of the second embryo was felt by the fully developed individual. (Ibid. p. 227, 231.) And this appears in no way impossible, when we consider that the new noses formed by the rhinoplastic operation are at first insensible, but gradually acquire feeling. Hitherto, it has never been observed, that both heads of a double-headed monster have exerted voluntary influence over the entire single trunk. The possibility of this occurring, however, at least in the lower animals, cannot be absolutely denied. It is, indeed, much to be desired, that some accurate observations should be instituted upon the double-headed Hydræ with single trunk, which, as Trembley has shown, may with great ease be artificially produced, by dividing longitudinally the cephalic end of a polype. In the branched Vorticella, Carchesium polypinum of Ehrenberg, which propagates by spontaneous longitudinal division, the separate individuals thus produced are seated upon one stem endowed with muscular contractility. In this animal, therefore, the subjection of one common trunk or stem to two centres of volition may, perhaps, exist.

c. Influence of the mind of the mother upon the fœtus.

The connection subsisting between the mother and the fœtus resembles that between the parent polype and the gemmæ or buds developed upon it, which have each an individual vitality, and gradually acquire an isolated condition and independent centres of action. The will of the parent trunk has no influence over the motions of the developed germ, and we have no more reason to expect such an influence in the case of the human subject and mammalia. In the Nais, which multiplies itself by spontaneous division, the part which subsequently becomes a new individual moves under the directing influence of the brain of the original worm; but this is a different case: it is not the development of a new organism from an unorganised germ, but the mere isolation of a part from another organism, to the will of which it has been subject.

The influence of the mind of the mother upon the nutritive processes of the fœtus must also be considered in this place.

The general question which should first be determined is, whether the influence of the mind is so extended that determinate ideas of physical and tangible phenomena are able to cause their own realisation by corresponding plastic changes in part of the organism.

That the mind has such an influence over the sensations and motions is beyond a doubt. But the question is, whether the idea of a special form with a particular colour can cause the organism to realise this form and colour by a change in a part of the skin of the body. This question is involved in that respecting the influence of the imagination of the mother upon the organisation of the fœtus; but in the latter case we are required to admit that the mind can exert an influence even external to the organism to which it belongs.

The cure of small organic lesions, such as warts, through the medium of the imagination, cannot be adduced in support of the affirmative of the above question; for

ures the mental idea does not produce a definite form, but merely excites an
of the natural nutritive process. The natural organic action being increased
l to the existence of a morbid growth, such as a wart; and, hence, the latter
But the imagination of the mother is supposed to produce some positive re-
modified structure, even in form corresponding with the efficient idea. That
nfluence exists is improbable, from the mere circumstance that it is supposed
from one organism to another; while the connection of mother and child is
nore than the closest possible juxta-position of two organisms in themselves
distinct, which exert an attraction on each other by their contiguous surfaces,
f which receives its nutriment and warmth from the other. But there are
er reasons which tend to refute this old and popular superstition. Nearly
onstrosities born in Prussia are brought under my observation; and, never-
can assert, that a new form scarcely ever presents itself, but, on the con-
t the great mass are constituted of certain kinds of monstrosities constantly
which belong to the great categories of arrests of development, divided or
s, defects, coalescence of lateral organs with deficiency of the intervening
. In the accounts given of these monsters, however, it is frequently stated
nind of the mother when pregnant was strongly affected by some object, and
n which this happened is described, although the monstrosity presents not
est resemblance to the object in question. Moreover, when we consider that
man during her pregnancy must certainly be frightened several times, and
many have once at least, if not oftener, a presentiment of evil from such
ithout any result following, we certainly must perceive that, when a monster
to be born, circumstances will not be wanting to afford an explanation of its
e conformably with the popular belief.

nly way, therefore, in which the mind of the mother can reason-
supposed to affect the fœtus, is by a sudden emotion in the former
ng an equally sudden change in the organic actions subsisting be-
er and the fœtus, so as to bring about an arrest of development
tter, or to fix its forms at certain transitory stages of metamor-
without the idea in the mother's mind having any direct influence
at part of the fœtus in which these arrests occur. Most monsters
ormally formed in several distinct parts, and frequently we find
of development in very different and distant parts of the same

e are correct in denying that ideas conceived in the mind of one
ed being, can be realised in the structure of another individual;
will be scarcely probable that one person can influence the
f another in any other way than by speech or signs. Even
it should be admitted, that organic beings may exert unknown
t are called "magnetic" influences on each other, and, perhaps,
t contact, through the medium of the nerves; still the communi-
of ideas or particular states of the mind from one person to
, as in the pretended phenomena of animal magnetism, &c.,
remain as improbable as it is inconceivable.

CHAPTER III.

OF THE TEMPERAMENTS.

temperaments are peculiar permanent conditions or modes of
reaction of the mind and organism. They are chiefly dependent

[illegible] hemorrhages. [illegible] persons, [illegible] disease. [illegible] arise from the [illegible], [illegible], hepatic, and nervous con-ı, and other abnormal predispositions of the body, from the temperaments of . There are many choleric persons, who, when labouring under emotion, any other organ sooner than the liver; who, for example, become affected ligestion, palpitation of the heart, or nervous tremors and twitchings. The ilious constitution of the body must exist in persons who have a yellowish ıe skin, and suffer disorder of the liver, not merely when they are affected ef and anger, but when they are subject to any mental emotion.

ding to my view the temperaments are entirely dependent on the different in which different individuals are disposed to the strivings and emotions rom the depression or excitement of the feeling of self; in other words, on rent degrees of disposition to the states of desire, pleasure and pain, and on ıt to which these states of the mind are promoted by the composition and the organs of the body. We have already stated it to be probable, that the or emotions of the mind are due to that fundamental property of organic which causes them to seek the integrity of self, and which, without even distinct sensations, yet influences the conception of ideas and enters into tion with them.

ı the organisation of an individual is such, that his mental strivings or emo- neither intense nor enduring, he is of the *phlegmatic* or unexcitable tempera- ı which the ideas of things, and the combinations of these ideas, remain more completely mere ideas, uncombined with any strong feelings of the restriction ısion of self,—unmodified by pleasure, pain, or desire. The phlegmatic tem- ıt to which we here allude, is by no means a pathological condition. In per- this temperament ideas are conceived with as much rapidity as in others, and ıy be the same power of mind as in other temperaments. When the intellec- ılties are good, this temperament will render a person capable of more dif- ;ts, and successful in a more extraordinary degree, than would be possible ;s impulses rendered stronger by a more passionate temperament. Such a whose mental strivings, or emotions, are not violent, remains cool and undis- and is not drawn away from his determined course to the performance of acts ıe would repent on the morrow;—he is more sure and trustworthy than persons pposite temperament, and his success more to be depended on; in times of and at moments of importance, when good judgment, calculation, and reflec- ɜ needed rather than very quick action, his powers are all at his command. ɜnergy of action, which is dependent on the susceptibility of the strivings of not to be looked for in a truly phlegmatic subject, such as I have described; ɔlace of it, all the good effects of delay and cautious calculating endurance. ıstances which would excite the choleric and sanguine to hasty passionate acts, uld cause them painful and bitter feelings, are regarded by the phlegmatic t emotion, exciting merely his meditation; so that he neither complains nor ıart in them, but pronounces dispassionate reflections upon mankind and their ons. He does not feel his misfortunes strongly, bears them with patience, and not affected in any great degree by the sufferings of others. He contracts few hips, but when he has formed them does not break them, and may be a per- ;rustworthy and useful man in society. Where rapid action is required the ıatic person is less successful, and others leave him behind; but when no haste ssary, and delay is admissible, he quietly attains his end, while others have tted error upon error, and have been diverted from their course by their pas- The phlegmatic person knows his proper sphere, and does not trespass on others, or come into collision with them. From this conduct, as well as from erly and steady course of action, in which he keeps his object in view, and self-deception, he derives a contented tone of mind, free alike from turbulent ıents and deep suffering.

at kind of phlegmatic disposition which is characterised by slug- ess, apathy, want of sympathy, irresolution, tediousness, difficult rehension, and slow mental progress, and which prefers pain not ly felt to labour and exertion, is an abnormal or pathological con- ı. The more excitable or unrestrained temperaments are the ric, sanguine, and melancholic. The passions are the manifestations of the emotions or strivings of the mind, and of the restraint or exaltation of these strivings, attended with feelings of pain or pleasure, and produced by ideas of particular objects. The striving of the mind may be so strong, and the attendant organic actions so inexhaustible, as to overcome all impediments, or the pleasurable or painful emotion may be intense, while the sensibility is excessive, and the reaction by continued strivings of the mind and organic action relatively feeble. In the first case the temperament is the choleric; in the second, it is either the sanguine or the melancholic, both of which are dependent on the same essential quality of mind, and more nearly allied to each other than to the other temperaments.

The choleric person exhibits a power of action remarkable both for intensity and endurance, under the influence of passions or desires which have reference to himself or others. His emotions are highly excited whenever he experiences any opposition or check to the strivings of his mind, whether these strivings tend to the extension of the power of self, or merely to the maintenance of its integrity; and his ambition, his jealousy, his revenge, and his love of rule, know no bounds as long as he is under the influence of passion. He reflects little, but acts unhesitatingly, either because he alone is right, or more especially because it is his will so to act; and he is not readily convinced of his errors, but persists unalterably in the course to which his passion prompts him until he ruins both himself and others.

In the sanguine temperament the main tendency of the mind is to the feeling of pleasure; while there is great excitability but little durability of the states of emotion when excited. An individual of this temperament is much the subject of pleasurable feelings, and seeks that which will excite them; he readily sympathises, and forms many friendships, but as readily relinquishes them; frequently changes his inclinations, and is little to be depended on; he is easily enraged, but as soon relents; promises readily and much, and is sincere at the time, but neglects his promises if they are not immediately performed; conceives many projects, but never executes them; is charitable towards the faults of others, and expects the same indulgence for his own errors; lastly, he is easily appeased, is open-hearted, amiable, good-tempered, social, and uncalculating.

The feeling of pain is the fundamental tendency of the mind in the melancholic temperament. The melancholic person is as easily excited as the sanguine, but in him painful sentiments are of longer duration and more frequent than pleasurable feelings; the sufferings of others excite his deep sympathy; he fears, repents, mistrusts, and has misgivings on every occasion, and pays especial attention to everything which favours this tone of mind. He is prone to fancy himself offended and injured, or neglected; impediments which he meets with render him dejected, timid, and doubting; and he loses the power either of acting or of judging. His desires are full of sadness, and of the feeling of having suffered a loss: his grief is immoderate and inconsolable.

These delineations of the principal features distinguishing the temperaments might easily be extended; but to enter into any further details would be exceeding the bounds of our proper field of inquiry.(*a*)

(*a*) The reader is referred to an able essay on *Temperaments* by Doctor Caldwell.

CHAPTER IV.

OF SLEEP.

The excitement of the organic processes in the brain which attends an active state of the mind, gradually renders that organ incapable of maintaining the mental action, and thus induces sleep, which is to the brain what bodily fatigue is to other parts of the nervous system. The cessation or remission of mental activity during sleep, in its turn, however, affords an opportunity for the restoration of integrity to the organic conditions of the cerebrum, by which they regain their excitability. The brain, whose action is essential to the manifestation of mind, obeys, in fact, the general law which prevails over all organic phenomena, viz. that the phenomena of life, being particular states induced in the organic structures, are attended with changes in the constituent matter of those structures. Hence, the longer the action of the mind is continued, the more incapable does the brain become of supporting that action, and the more imperfectly are the mental processes performed, until at length sensations cease to be perceived, notwithstanding the impressions of external stimuli continue. This is entirely analogous to what frequently occurs during the waking state in the case of individual sensations. A coloured spot regarded steadfastly for a long time becomes at length invisible, and nothing more than a general impression on the retina, without defined details, is perceived. In persons of feeble nervous system long direction of the sight to one object causes the whole field of vision to become dark. Not merely the action of the mind, but the long-continued exertion of other functions of animal life, such as the senses or muscular actions, induces the same exhaustion of the organic states of the brain, and thereby want of sleep and sleep itself; for these different systems of the body participate in the change which the organic condition of any one of them may undergo. Lastly, impairment of the normal organic state of the brain by the circulation through it of blood charged with imperfectly assimilated nutriment, as after full meals in which spirituous drinks have been taken, also induces sleep. The narcotic medicaments act still more strongly by the change they produce in the organic composition of the sensorium. Even the increased pressure of the blood upon the brain, produced by the horizontal posture, may become the cause of sleep. In many persons, for instance in myself, sleep is brought on at will by the assumption of the recumbent position, while the thoughts are kept in an unexcited state.

The duration of the periodical state of sleep, and the time at which it occurs, are dependent partly on external and partly on internal causes. Sleep generally occurs at night-time, while the waking state is coincident with day, on account of the senses, and consequently the brain, being subject to many causes of excitement during the day, but to few or none at night. The causes which determine the duration of sleep and waking are seated, however, in the organism itself. The day may become the state of sleep instead of night; and if a person keeps himself in a state of activity night, he will sleep as long by day as he would otherwise have slept by night. moreover, the nature of many animals, for example, of the so-called nocturnal to be in action during the night, and to rest by day.

The periodical recurrence of sleep and the waking state is, therefore, essentially connected with something in the nature of animals, and is not dependent on the simple alternation of day and night. But the periods of sleeping and waking, in accordance with a pre-established harmony of nature, have been made to agree with those of the earth's revolutions.

In this respect the short period of twenty-four hours, during which the alternation of sleeping and waking occurs, corresponds to the longer periods of alternate rest and activity which animals present in the rut, in their migrations, in the changing of their feathers (moulting) and hair, and in hybernation and the summer-sleep. For, although hybernating animals fall into the torpid state on account of their inability to maintain undiminished their state of vital activity and power of developing heat without the aid of external warmth, yet, even in them, as the experiments of Czermack and Berthold have shown, there is an internal cause resident in the organism itself, which renders periodic rest necessary for the restoration of their excitability. The rellmouse, *Myoxus glis*, frequently is torpid in the summer; and the dormouse, *Myoxus avellanarius*, hybernates in the winter, whether it is in the open air or kept in a heated chamber; the only difference being that the sleep is more profound in a cold atmosphere, and comes on earlier than in the heated room. In the open air the animals become torpid as early as October; while in the warm room they wake every day for a certain time until about the middle of December, when the sleep becomes more and more continued, and deeper, so that it is not again interrupted, or only very rarely, before the middle of March. The cause of hybernation, therefore, according to Bertbold, is not external cold alone, nor the want of food, but a general deficiency of vital energy, analogous to that displayed in the moulting of birds and similar phenomena, and connected with the changes of the seasons. (See *Müller's Archiv.* 1835, p. 150; 1837, p. 63.)

The daily sleep of plants, and their winter sleep, present in this respect exactly similar phenomena, and prove that neither the internal tendency to periodical phenomena, nor the dependence on external stimuli, is peculiar to organic beings supplied with nerves and a central source of action.[*]

The waking of plants is manifested by the expansion of their leaves, and the turning of their upper surface towards the light. The sleep of plants, first noticed by Cordus, and afterwards observed by Linnæus to be a general phenomenon, consists in the leaves assuming the erect position, and folding themselves together. During the day, also, plants inhale carbonic acid, and exhale oxygen, while at night they absorb oxygen from the atmosphere. The movements attending the sleep of plants are most evident in the youngest leaves of the stem, and in the petals of the flowers, and least manifest in the older leaves. The sleep of young animals, also, is most profound. There are plants, as well as animals, which sleep through the day and are awake by night; the stimuli afforded by day being in both cases less adapted than the conditions of night to maintain the activity of the organism. In most plants, as in animals, sleep is the result of the state produced by the continued stimulus of light, and of the absence of this stimulus during the night-time. For, according to the experiments of Decandolle, the period of the sleep of plants may be reversed by producing artificial night and artificial day. But still there is a cause both of the sleep and waking seated more deeply in the organism itself. From the observations of Duhamel, Ritter, and Decandolle, we learn that the leaves of plants kept in constant darkness, open and close their leaves at regular intervals.

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[*] See the instructive paper on the sleep of plants, by E. Meyer, in the Vorträge aus dem Gebiete der Naturwissenschaften und der Œconomie, herausgegeben von C. von Baer. Königsberg, 1834, p. 127.

In general characters, the sleep of animals and that of plants resemble each other. There are, however, points of great dissimilarity. The position which the leaves assume during the sleep of plants is the same which they have when young, and as yet unfolded. But this position in sleep is not the result of relaxation; for it does not easily admit of being changed, so that the leaves break off in the attempt. Moreover, in the sensitive plants, the position which the leaves have during sleep is the same that they take when irritated. A stimulus applied to a sensitive plant at one spot, in such a manner as to give no mechanical shock to the whole plant,—for instance, the stimulus of heat applied by means of a convex lens,—is propagated gradually to other parts, the leaves closing in succession, according as they lie at a less or greater distance from the irritated point.

The sleep of animals is a phenomenon dependent on a change in the animal part of the organism alone. All the functions of organic life—namely, the processes ministering to nutrition, with all the involuntary movements attending them,—pursue their ordinary course. Even the involuntary movements of the animal system of muscles, such as those of respiration, and many other movements of the same kind, as we shall presently show, do not partake of the repose of sleep. The organic system has its periods of remission and rest, but these are not coincident with the sleep of animal life, and are very different for different organs. The heart has its period of rest after each beat; the intestines and uterus have theirs, also, at different times; and the change and new formation of the hairs and feathers show us that the nutritive processes, also, have alternate periods of rest and action. Even the growth of a single tooth, spine, or feather, presents to us a cycle of states, in which the formative process has different degrees of activity. For, during the formation of the shaft of the latter organs, or the fang of the tooth, the nutritive action can be by no means the same as at the time when the crown of the tooth, the point of the spine, or the barb of the feather, is formed. In animals whose hair is knotted, like the vibrissæ of the seal, the nutritive process, on which their growth depends, must consist of a regular succession of alternate remissions and exaltations, since these structures grow only at their root.

All the phenomena of organic life, and, indeed, all the phenomena presented by the animal body, with the exception of the true animal functions which are under the influence of the mind, obey, like the development of the germ, a law of absolute necessity; although, like it, they conform to a well-adapted plan; and the nutrition and maintenance even of the organs of animal life are not dependent on the operations of time, mind or intellect. We may, therefore, regard sleep and the waking state, as the result of a species of antagonism between the organic and the animal life; in which the animal functions, governed by the mind, from time to time become free to act, while at other times they are repressed by the organic force acting in obedience to a law of creative nature. It is true that even in the waking state the organs of animal life are under the dominion of the organic force; but the different properties of the muscles and cerebro-spinal nerves, which are the result of organisation, are engaged in actions very different from those of the organising process. In sleep, on the contrary, when these animal functions entirely, or for the most part, cease, the organic processes are almost the only ones which continue; and, during that state, even the organs of animal life are rendered capable of renewed action by the operations of the organising force, which proceed without the consciousness of the animal, though accordant with a well-contrived plan and with reason.

In consequence of all parts of the organism participating to a certain extent in the states of excitement which affect primarily only one part, the waking of the system of animal life, and its consequent increased excitement, must be gradually imparted to those organs which are under the influence of the organic nervous system; and any functions which these organs may perform, in addition to the mere process of organisation, will be in some measure affected. Hence it is that the heart's action becomes rather more frequent at the time of waking than it was during sleep. The radiation or extension of excitement from the animal system to the organic ceases during sleep, and so far the organic part of the body has at that time a remission of action, though in a less degree than the animal system. If the waking state of the animal system is maintained much longer than natural, this extension of excitement from it to the organic system not merely becomes more manifest, (for instance, in the acceleration of the heart's action,) but the great exhaustion of the organised material by continued action is imperfectly balanced by the organising process. Hence the signs of defective nutrition, which soon show themselves when watching is long protracted.

Having considered thus far the nature of sleep generally, we will now study more minutely its phenomena. On the commencement of sleep the senses cease to perceive external impressions, and the play of ideas, and the emotions, are entirely or in greater part silenced. The will ceases to rule the muscles; the eyelids, which experience the sensation of fatigue, are no longer under command; the head droops, and this state of inaction soon extends over the whole animal system of organs.

When sleep is perfect there is generally a complete absence of voluntary motion; while the involuntary movements of the organic muscles, and those movements of certain animal muscles which are only in part under the influence of the will, such as the respiratory movements, continue; the movements last-mentioned merely ceasing to be influenced by volition. The movements of the heart, and the respiratory movements, are somewhat less frequent than in the waking state. The action of some animal muscles is increased during sleep, they being apparently released from some counteracting force which opposed them in the waking state. Such is the case with some of the muscles of the eyes, as well as with the muscles of the extremities in birds which sleep standing on one or both legs. During sleep the eyes have a peculiar position. At that time, as well as in a state of mere sleepiness, both eyes are turned inwards and upwards. This movement is still more strongly displayed in disorders of the nervous system; for example, in epilepsy and catalepsy. This position of the eye during sleep also gives it a very different expression from that which it has in death. The iris is contracted in a person asleep, and the pupil consequently narrowed; but on his awakening the pupil always dilates, becoming first, indeed, very wide, and then undulating, until it acquires the mean size which it has in the waking state. (See page 535.) A greater amount of external warmth is required for the body during sleep than at other times; and immediately after the awakening from sleep there is frequently great sensibility to cold.

When, during sleep, the conception of ideas by the mind does not entirely cease, dreams arise. These are for the most part composed of simple ideas and emotions; but general notions sometimes come into play, and movements affected by the animal muscles may be combined with the ideas as in the waking state. This condition of the mind is "dreaming," as long as the sensorium is disturbed by something which gives to the operations of the mind a character opposed to that of the ordinary conceptions and thoughts of the same person. The ideas conceived in dreams so far resemble those of the waking state, that they may refer to any period of the past life; just as in our ordinary condition we may look back to all periods of our life, and think at one moment of yesterday, and the next of times years past. If the ideas which occupy the mind during the waking state have a certain degree of persistence, the same ideas will recur in dreams during sleep. The dreams of some persons, on the other hand, refer chiefly to times long past. Many blind people, after they have been some time deprived of sight, cease to dream of visible objects, but their dreams accord with their present mode of intercourse with the external world. Other individuals, who have lost their sight, continue through their whole life to dream of visible objects. The important circumstance, therefore, regulating these dreams of visible objects by blind persons, is not the time which has elapsed since the sight was lost; for Huber, who had been blind since his eighteenth year, when in his sixty-sixth still dreamed of objects which appeared distinctly visible to him, though these dreams referred to the time at which he was possessed of vision. The facts which we learn from such cases are, that the internal parts of the apparatus of vision are alone essential to the production of phantasms, and that ideas recur, which were originally conceived previously to the loss of sight. (See *Froriep's Notizen.* 888, p. 118.)

In the simplest form of dream the action of the mind is confined to the mere conception of simple ideas, to the exclusion of general notions;—an inferior kind of intellectual action, which characterises the mind of brute animals, and also, for the most part, the human mind in the state of intoxication, on account of the disturbance of the organic conditions of the brain in that state. These dreams are accompanied by phantasms. The senses which are thus excited by internal causes may also be called into action by external causes of adequate intensity; but these external impressions, on account of the weakness of the reasoning faculty during sleep, suggest incorrect ideas. A person asleep feels himself in an uneasy position, and believes that he is bound and held down by force. His arms are folded one over the other, and he thinks they are held so by another person. In such cases, the images of persons performing the actions thus conceived in the dream are also produced. Again, the sensation of the urinary bladder being full may be perceived during sleep; but the dreamer, believing that he is awake and out of bed, is led by this sensation actually to evacuate the urine. The increased excitement, of which the sexual organs are from time to time the subject, gives rise to the conception of corresponding images even in dreams. The lamp burning during sleep and the extinguishing of it also exert an influence upon the images conceived in dreams. The cessation of a noise to which the sleeper is accustomed, such as the sound of a mill, excites ideas in the mind in the same way as a sudden noise occurring after previous silence. The serenade and its cessation are both perceived during sleep; but incorrect ideas and phantasms are connected with these sensations, which become interwoven in the web of our dreams.* The predominant emotions of the mind, also, influence the character of the dreams. When the mind is under the sway of depressing passions, the dreams will have a terrible or mournful character.

Sometimes we reason more or less correctly in dreams. We reflect on problems, and rejoice in their solution. But on awaking from such dreams, the seeming reasoning is frequently found to have been no reasoning at all, and the solution of the problem, over which we had rejoiced, to be mere nonsense. Sometimes we dream that another person proposes an enigma; that we cannot solve it, and that others are equally incapable of doing so; but that the person who proposed it, himself gives the explanation. We are astonished at the solution which we had so long laboured in vain to find. If we do not immediately awake, and afterwards reflect on this proposition of an enigma in our dream, and on its apparent solution, we think it wonderful; but if we awake immediately after the dream, and are able to compare the answer with the question, we find that it was mere nonsense. I have, at least, several times observed this in my own case. In dreams in which we seem to hold a conversation with other persons, the remarkable circumstance is, that the arguments and counter-arguments which rise in the mind, are connected with the ideas of the corresponding persons, just as notions are associated with certain signs. It occasionally happens in such dreams that questions are asked, and no answer given, because we are ourselves unable to answer them. (*Compare Prevost's Remarks, loc. cit.*) Sometimes possible combinations of circumstances are presented to our minds in dreams, with the character of forebodings, and with all the distinctness of reality; and as anything which is possible may become actual, these circumstances may really occur without there being anything wonderful in the matter. For instance, if we are much interested in a person, and regard him with some kind of emotion, know him intimately though not perfectly, and, though we think him honest and sincere, have, nevertheless, conceived it to be remotely possible that he is the reverse; this person may, in our dreams attended with phantasms, appear in situations which show him to be dishonest and insincere: and if it should afterwards be proved that such really is the case, the dream appears wonderful, although it is nothing more than a play of ideas excited by a leading thought, which is cherished with the passions of fear and love. Sometimes the sick perceive in their dreams countenances of beneficent persons who advise them to adopt this or that proceeding; and the measures thus suggested occasionally prove successful. Physicians, however, who frequently meet with such prophetic dreams, have remarked, that they in many instances prescribe for themselves measures which are manifestly injurious, and which, therefore, are not carried into effect.

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* Various other examples are adduced by Prevost, from the observation of his own dreams. Biblioth. Universelle, 1834. Mars. Froriep's Notizen, pp. 888, 889.

The indistinctness of the conceptions in dreams is generally so great that we are not aware that we dream. The phantasms which are perceived really exist in our organs of sense. They afford, therefore, in themselves as strong proof of the actual existence of the objects they represent, as do our perceptions of real external objects in the waking state; for we know the latter only by the affections of our senses which they produce. When, therefore, the mind has lost the faculty of analysing the impressions on our senses, there is no reason why the things which they seem to represent should be supposed unreal. Even in the waking state phantasms are regarded as real objects when they occur to persons of feeble intellect. On the other hand, when the dreaming approaches more nearly to the waking state, we sometimes are conscious that we merely dream, and still allow the dream to proceed while we retain this consciousness of its true nature.

It very frequently happens, that in our dream we seem to be incapable of executing certain movements which we desire to perform. For example, we desire to escape from a danger, but cannot move; here the dream corresponds to a real state of the sensorium, which is in sleep unable to determine the nervous actions necessary for voluntary motion. Some persons, however, have in dreams a certain command of voluntary motion; and, while they sleep and dream, talk confusedly, or, sometimes, even coherently. The same exertion of voluntary power, also, is required by persons sleeping in difficult postures: for instance, by postillions sleeping, as often happens, on their horses; also by birds, which sleep standing, sometimes only on one leg. In fact, it is necessary to constitute sleep and dreams that a very large portion of the ideas which can be called into action in the waking state should be passive; but those ideas which are active may, unless the sleep be very deep, call the organs of motion into activity. The near connection of the different pathological states of sleep with each other is here rendered manifest. The speaking of distinct coherent words during sleep, the rising from bed, and the performance of different acts in that state, are all phenomena of exactly the same kind. The somnambulist is scarcely to be separated from the *somnostatist*,—the bird standing while it sleeps.

The simplest degree of somnambulism is observed in children of excitable nervous system, who, while they yet sleep, become restless, call out, cry, and are quieted and comforted by persons speaking to them, whom they understand, and even recognise when their eyes are open; although, notwithstanding they are thus capable of voluntary movements and susceptible of ideas from external impressions on their senses, they do not for a long time awake from the dream which has alarmed them. In this case the mind is in a certain degree awake, but there are not at first present ideas of sufficient distinctness to restore the mass of ideas, disturbed by the dream, to a state of equilibrium. This state is similar to that of a person just awaking from sleep, with whom we may converse, although he gives confused answers, and confounds what is going on around him with the images and ideas which belonged to his dream

In more extreme degrees of somnambulism, the dreamer rises and performs all the acts of life under the guidance of those ideas which are in an active state, and of the sensitive impression connected with those ideas. He performs acts determined by his dream, and when they are attended with danger he is unconscious of it; he crosses, for example, narrow planks, as a child would do, that is not aware of danger and therefore does not tremble. It is not really very difficult to walk over an inclined plane, if we do not know that it is greatly elevated above the ground; and we should be able to walk over many roofs if they were placed upon the ground. The somnambulist associates only ideas which bear some relation to those already in action. No other ideas exist for him. He sees and hears; but is disturbed by nothing which is foreign to the train of ideas which constitute his dream, unless he be actually awoke.

Sleep ceases as soon as the susceptibility of the brain for those organic states, which are necessary for the play of ideas and reasoning, is perfectly restored. The condition of the various parts of the body is then again distinctly perceived. But sensations of sufficient intensity produced by external objects, or even strongly excited ideas in dreams, will arise from sleep which is not normally at an end. Strong emotions felt in dreams, such as fear and other passions, very frequently put such an abrupt end to sleep. The emotions here excite actions of the body, as in the waking state, and a stronger and increasing excitement is thus diffused through the system of the sleeper, which at length frees the brain from its fettered state.

As soon as we awaken, we analyse the first impressions on our senses, think where we are, whether in this or that chamber, and consequently whether in this or that town; we try next to recollect what time of day it may be, and correct the errors which we may in the first instance fall into with regard to this question. Sometimes the play of the ideas during sleep is so limited, and so completely unconnected with the ordinary ideas respecting the individual existence of the sleeper, that on awaking he has to collect the ideas having reference to his individuality in order to know who he is.

Sleep, in a greater or less degree, as Aristotle correctly remarked, falls to the share of all animals. (*De Somno et Vigiliâ.*) Some brute animals even dream; the dog, for example, barks in his sleep. In some, the periods of sleep are less distinct and regular; and this is particularly the case in the cold-blooded animals. They, however, appear to be subject to states analogous to sleep. Frogs, which croak a part of the night during summer, generally become quiet after midnight, especially when the pairing season is passed. Insects and spiders are frequently found in a lethargic or torpid state; and it is probable that all animals in which no regular periods of sleep and waking have hitherto been observed, have an equivalent for sleep in the state of inactivity and rest which they from time to time present.

To return to man.—Persons in whom the organic functions predominate, who are stout and full-blooded, sleep longer and require more sleep; and the contrary is the case with thin persons. Individuals of excitable, but at the same time energetic constitutions, and who are with difficulty fatigued, require less; those of an excitable, but more readily exhausted habit of body, require more sleep. In youth sleep is longer, and is more indispensably requisite, than in old age. This difference seems to depend on the greater predominance of the nutritive organic functions in youth. Hence the greater length of time passed in sleep by the new-born infant. This disposition to sleep is constant in the child as long as the organising action finds material in new nutritive matter supplied by food: and the child awakes when it requires nourishment. In the adult, also, abundant food induces sleepiness, partly by giving increased activity to the organic functions, and thereby disturbing the reaction of the animal functions, and partly by the pressure which the crude and imperfectly assimilated nutriment newly introduced into the blood exerts upon the brain. As causes favouring sleep, we must reckon also the impressions made on the sensorium by general stimulants of the skin, as friction of the surface, baths, &c., and the effects produced on the sensorium from within by sedative and narcotic medicines.

BOOK VIII.

OF GENERATION.

SECTION I.

OF HOMOGENEOUS OR NON-SEXUAL GENERATION.

CHAPTER I.

Of the multiplication of organic beings in the process of growth.

a. In Plants.—The leaf must be regarded as an individual organism, containing in "essence" or "potentially" all that is comprehended in our notion of the species of plant to which it belongs, and capable of propagation by the development of branches. Almost all the organs of plants, indeed, are leaves; even the different parts of the flower are shown by the theory of the metamorphosis of parts to be leaves modified in form and function. On the other hand, however, the stem itself, when stripped of all its leaves and branches, cannot be looked upon as an aggregate of mere imperfect fragments of individuals. In this truncated condition the stem is still a multiple of the germ. For leaf-buds may be developed and sprout even from a stem thus truncated. All these facts, therefore, confirm the truth of the proposition, that the fully developed plant is a multiple of individual plants,—a compound system of individual organisms, the essential parts of which are certainly contained in the leaves, though they exist also in the stem when stripped of its leaves.

b. Animals.—The power of multiplying the vital force resident in the germ is not peculiar to plants. Animals, and it would seem all animals without exception, possess the same property. There are many instances in the animal kingdom in which the multiplication of individuals in the process of growth is quite as distinct as in vegetables; but in other cases it can be proved to take place only by induction from a series of facts. The young polype developed from the ovum or gemmule of a compound polypiferous animal is at first a single individual, actuated by a single independent will. But in proportion as this young creature appropriates to itself new matter and grows, it becomes transformed into a multiple system of individuals, like that presented by a full-grown plant, and is then evidently regulated in its movements by many distinct centres of volition. A common stem unites all the component simple animals, and in the Sertularia the cavity of this stem communicates with the cavity of each polype, while out of its wall new polypes sprout. Those compound polypes which consist of a mere aggregate of independent simple animals, united into one mass, are not referred to in the foregoing description.

We now proceed a step further, and find animals which in form appear perfectly simple, and have only one directing will, but nevertheless are systems of parts endued with individual life, and capable of propagating the form and organisation of the species. In these animals the component parts or segments undergo multiplication during the process of growth, and a certain number of them becoming separated, whether spontaneously or artificially, preserve the faculty of individual life. The parts thus separated were for a time subject to the will of the parent animal, and in that respect were mere members of its body; but, when about to separate themselves from the rest of the system, they acquire a more intimate relation to each other, become actuated by a distinct will, and have, as it were, their own proper centre of action, even while they form part of the body of the parent worm. At length they become detached, and display free voluntary motion. The young individual thus produced consists at first of few constituent parts or members; grows, however, by the appropriation of new matter, and forms another compound system capable of dividing spontaneously or of being divided into several portions, "potentially" endowed with individual life. For a time this multiple individual is subject to the influence of a single will, and is only so far a multiple animal as the parts which compose it have the capability of becoming independent individuals, which as yet they are not "de facto." Subsequently, the individual parts, though still unconnected, are actual independent beings. Many Annelida and Entozoa may, indeed, be divided artificially into several distinct individuals, and are, therefore, not really simple animals, but systems of parts, each of which, however small its size, contains all that is essential to the idea of an independent organism, and has the power of producing an organism of the same species.

The question here presents itself: how small a portion of an organic body may contain the force necessary for the reproduction of the species? In the higher animals which propagate only by sexual generation, this force resides only in the germs of the ova, which are large cells containing the "germinal vesicle," and its nucleus, or the "germinal spot" of Wagner; while all other parts of their body, however large or small, are destitute of the reproductive power. In those plants and animals which propagate their species by buds or sprouts, the germ consists of a mass of cells which may be produced at almost any part of the body of the parent. In some of the lower animals the same reproductive power is possessed by every aggregate of organic elementary parts, that is of such elementary parts as were originally developed from similar cells, but which subsequently have acquired the form and properties of muscular and nervous fibres, and of fibres of cellular tissue, &c. In the lowest organic beings the power of producing new individuals is not merely manifested by separate portions of most parts of the body, but in some cases subdivision, even into the ultimate particles of the organism, does not destroy this power: isolated elementary particles are adequate to the propagation of the species. In plants, generally, all the tissues are produced from cells; but there are plants in which any single cell, separated from the rest of the organism, suffices for the reproduction of the entire plant, if nutritive matter be supplied. We have examples of this in the filiform fungi, such as the fungus of mould and the vegetable, which, according to the observations of Cagniard Latour and Schwann, forms the active part of yeast, and the growth of which in large quantity gives rise to the fermentation of saccharine liquors. This fungus of yeast consists of cells arranged in simple or branched threads; and it grows by some of the cells developing upon their free surface a small prominence which becomes a young cell. This young cell soon attains the perfect size, but has scarcely reached its full development before it, in its turn, begins to put forth a bud, which is the germ of the next cell. Single cells of this kind also separate themselves from the threads of which they formed part, and still in the isolated state form new cells by the process of budding, and thus propagate their species. All this process takes place so rapidly, that its different steps may be watched by means of the microscope. (*Poggendorf's Annalen*, xli. p. 184.) The same phenomena are presented by all the simple fungi. The dust-like powder of the fungus so destructive to silkworms, the muscardine, is composed of cells endowed with the power of reproducing plants of the same species; hence we may easily conceive that a single grain or cell of this powder, introduced into a brood of silkworms, may cause their entire destruction. (See *Audouin*, *Annal. des Scienc. Nat.* 1837.)

CHAPTER II.

OF THE MULTIPLICATION OF INDIVIDUALS BY THE DIVISION OF PERFECTLY DEVELOPED ORGANISMS.—FISSIPAROUS GENERATION.

Since organic beings in the fully developed condition are virtually multiples of the germ which produced them, they are capable of multiplication by mere division, without the formation of new germs. This fissiparous generation is observed in animals quite incapable of the development of buds or "gemmæ." It may be the result either of the artificial interruption of contact and organic reaction between the different parts of a body, or of spontaneous division. In either case the separation may be complete, or only incomplete. When it is incomplete, the organic being appears as a compound or multiple system, the independent individuals of which are still connected by a common stem.

1. *Artificial fissiparous generation.*—The increase of organic beings by spontaneous division, which occurs for the most part only in the animal kingdom, is a less easy process than the multiplication by artificial division. Artificial division produces absolute interruption of continuity between parts which have already undergone perfect organisation, and at the same time are equally endowed with vital force; and it thereby causes the force resident in each part to assume an active state, so as to produce a new organism. Polypes, therefore, may be divided in any direction, and the separated portions will develope new individuals. While, on the contrary, spontaneous division always takes place in certain determinate directions, in which it is productive of the least disturbance of the internal organisation.

Multiplication of all plants, and of many of the lower animals, may be effected by artificial division. Branches, twigs, or sprouts, separated from a tree, are organisms which continue to live and maintain the species, when they are either planted in the ground or engrafted upon another plant. These cannot, however, be properly adduced as examples of true multiplication by division, effected independently of previously formed buds; for cuttings of plants are generally provided with fully-formed leaf-buds.

Multiplication by artificial division in animals is most likely to be successful when the organism consists of a succession of parts of similar structure, the number of which increases during growth. Annelida and Entozoa, for example, have this conformation, and transverse sections divide them into segments, each of which still contains similar though shortened portions of the nervous system, blood-vessels and intestinal canal.

2. *Natural or spontaneous fissiparous generation.*—Spontaneous division takes place, for the most part, either transversely or longitudinally, or in both directions at the same time. It is only in animals that this mode of generation occurs to any extent, and hence it has been employed, together with other characters, by Ehrenberg as a means of determining in doubtful cases whether simple organic beings belonged to the animal or to the vegetable kingdom. Fissiparous generation is a very common mode of multiplication amongst the infusoria, though they also propagate by ova. Sometimes the gemmiparous mode of generation also is observed in the same genera. The higher animals never multiply by spontaneous division; and even the Rotatoria

present no instance of it, though it occurs again in the Annelida. The complexity of the process must be greater in proportion as the organisation of the animal is more complex, as there is less repetition of similar organs in its different parts.

CHAPTER III.

OF THE PROPAGATION OF THE SPECIES BY BUDS OR GEMMIPAROUS GENERATION.

The formation of buds is essentially due to the following process:—A portion of the substance of an organised being, which is superfluous for its individual life, separates itself in an undeveloped state of organisation from the organism of that being, so far as to assume a special individuality of life, without, however, losing its organic connection. From the germ thus produced the special organisation of the species is subsequently developed in the form of a new individual, which may either retain its organic connection with the parent trunk or become detached. This production by one living individual of the germ of a new living individual, presupposes that the parent trunk already contained within itself the organic force for several beings, and was, in fact, a virtual "multiplum." The process of the formation of buds, though a variety of imperfect spontaneous division, differs from the true fissiparous mode of generation. For, in the latter process, the perfectly developed organism divides into two, or more, perfectly organised segments. Here, therefore, the entire production of a special structure in the separated parts is not required, since the special organisation already exists, and only needs such changes as will restore to integrity the parts involved by the line of division; while, in the process of the formation of buds, the new individual represented by the bud is not perfectly organised, but is merely endowed with the power of developing a perfect organism. The bud of a plant is, therefore, to use the words of C. Fr. Wolff, the "simple plant," and the bud put forth by an animal, the "simple animal." A bud originally consists merely of the primary elements of all organisation, namely, cells, and contains even these in proportionally small number. The buds of plants are masses of ordinary vegetable cells. The vessels of the parent plant have not the least share in the formation of the original bud, and have no connection with it until a later period. The bud appears in fact originally to be a mere prolongation of the cellular tissue of the pith, as Duhamel, Treviranus, Meyen, and others state. It is not separated from the pith of the mother plant by any septum; merely cells of smaller size being interposed between them. (See *Treviranus*, *Physiologie der Gewächse*, b. ii. p. 630.) Usually the buds of plants are developed upon the parent stock, but sometimes they fall off and are developed separately, as in the cases of some monocotyledonous and dicotyledonous plants and the Hepaticæ.

The ovum is distinguished from the bud not only by the circumstance of sexual influence being necessary for its development, but also by its inability to undergo further evolution while forming part of the parent organism, and by its being insulated from the parent plant by distinct membranes. The spores, developed independently of sexual intercourse by many of the more simple plants, cannot be regarded as germs of ova.

1. *Of the formation of "buds" or "gemmæ" in plants.*

a. Buds of the inferior or non-vascular plants.—The buds of the plants of low organisation consist partly of aggregates of cells, partly of single cells.

b. Buds of the more highly organised vascular plants.—Axillary and Terminal buds.—The buds (leaf-buds) of the higher plants are either formed in the axes of leaves, or at the extremity of the stalk or stem. The leaf-like structures which sometimes appear as scales enveloping the apex of the axis of the bud or the embryonic nucleus of the future axis, may be absent, in which case the nucleus of the bud is naked. This body is formed of cells which, by spontaneous development, become the new sprout. The cellular pith of the stem of the plant is continuous with the cellular nucleus of the axillary and terminal buds. The development of the special organisation of the plants from the cells of the existing buds is always attended with the formation of new buds for the next period of vegetation. (See *Meyen*, *Pflanzen-physiologie*, b. iii. pp. 5, 7.) In the production of the special structure of the species, therefore, something in addition is always generated, which does not form a component element of the present organism, but contains the organic force for future vegetation.

2. *Of the gemmiparous generation of animals.*—In the animal kingdom, the propagation by the formation of gemmæ or buds is met with to the greatest extent in the class Polypifera, and less frequently in the Infusoria; for example, in the Vorticellinæ. Sars observed its occurrence in Cytais and other of the Acalephæ. Of the Entozoa the order Cystica alone presents examples of this mode of propagation. In Cœnurus, the vesicles which bear the numerous heads are at the same time germstocks, upon which the new individuals are developed as buds. In Echinococcus, the parent animals take the form of vesicles, on the inner or outer surface of which new individuals are developed, and to which they are for a time connected by a thin filament; but, subsequently, the young ones become free.* Hence the old Echinococci have the form of vesicles containing other vesicles, and have been incorrectly called acephalocysts.

SECTION II.

OF SEXUAL GENERATION.

CHAPTER I.

Of the Sexes.

In sexual generation the germs, though endowed with the power of propagating the distinctive properties of the genus and species, and even of the individual, are incapable of undergoing their destined organisation until they are acted on by another substance allied to them, though distinct in its nature from them, namely, the semen. The semen itself also propagates the peculiarities of the genus, species, and individual, but only by means of its influence upon the ovum, which is the immediate seat of all the changes attendant upon the production of a new individual.

The semen and ova are sometimes generated in different individuals, in which case fecundation is effected by the concurrence of the two sexes, or by the contact of the semen of the one sex with the isolated ova of the other, brought together artificially out of the body. Sometimes both semen and ova are formed in different organs of the same individual, which is the case in all hermaphrodite plants and animals. Dualism of the sex, therefore, does not necessarily involve dualism of the individuals; on the contrary, sexual generation, as well as multiplication by buds and division, may be effected in a single individual.

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* See J. Müller, in Müller's Archiv. 1836. Jahresb. CVII. Von Seibold in Burdach's Physiologie, b. ii. 2to. Auflage.

The individuals of the two sexes in each species of animal are generally distinguished by peculiarities of form, and often also by peculiar colours, or even by difference of size. Sometimes the female is larger, occasionally even to an extraordinary degree larger than the male, as is the case for example in the genus Lernæa, where the tiny male remains through its entire existence fixed over the orifice of the sexual organs of the female. (See *Nordmann*, *Microgr. Beiträge.*) In other instances, as in many birds, the male excels the female both in his size, strength, and beauty of his markings.* The most important differences, however, between the two sexes are those evinced in their instincts, which are more constant than the differences of form. The female is entrusted with the protection of the offspring, and for this purpose dreamlike incentives to action, or instincts, arise in her sensorium. As soon as the egg is laid and seen, the female bird feels an instinctive attachment to it, and never leaves it except for short periods. The females of mammalia have the same maternal instinct after the birth of the offspring. The young animal seems to form part of its mother, who protects and defends it in all dangers. The entire or principal care of the young belongs for the most part to the female; and the case of the male Alytes obstetricians, which bears the ova upon its feet, is a rare exception.

The male of the human species is of larger proportions, stronger build, and more marked outline than the female; has respiratory and vocal organs of larger dimensions; is less easily affected by external impressions; and is in every respect not only physically but also morally of greater strength. He yields less easily to pleasant and unpleasant or painful feelings, is more energetic and constant in his efforts and desires, and more courageous; but he is also more selfish, and more ambitious of honour and fame. He excels the woman in capacity for all intellectual labours and in fruitfulness of mind; and is more cautious, systematic, and reserved in his intercourse with his fellow-men, more difficult to turn, and more haughty; but at the same time more upright and magnanimous. The field of his activity lies in the intercourse and contest of human faculties,—in the relations of society.

The woman, more delicately formed, is weaker both in body and in the faculties of the mind than the man; she is more excitable and sensitive, more timid and pliant, more superstitious, more vain, more excited by feelings of pleasure and disgust, and less so by desires. She is gifted with finer feelings of propriety and adaptation, and with a lively imagination; but is without the creative power and the clearness of intellect of the man; while, on the other hand, the reproductive power of her body is greater. Friendship towards her own sex is rare in woman, but her love for her husband and children is proportionately strong; so that her whole mind may be occupied by those feelings. Moreover, woman is distinguished by her modesty, meekness, patience, and amiability; by her readiness to sacrifice her own good and herself for the sake of others; by her tenderness, sympathising disposition, and piety. The field of her activity is her home and family. (Compare *Rudolphi*, *Physiologie*, bd. i. p. 259.)

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* For an account of the varieties presented by the animal kingdom in this respect, consult Rudolphi's Beiträge zur Anthropologie. A complete history of the phenomena of the sexes will be found in Burdach's Physiologie, bd. i.

We have already seen how the male and female reproductive substances, the semen and ovum, differ from the bud or gemma. The former, like the bud, have the faculty of reproducing the form of the parent organism; the semen, namely, gives the individual peculiarities of the male, and the ovum those of the female. Unlike the germ of buds or gemmæ, however, both the ovum and the semen are imperfect, inasmuch as neither can manifest the reproductive power until it is united with the other. In hermaphrodite animals the two imperfect substances which are thus complementary of each other are formed in the same organism; in animals with distinct sexes they are formed in different individuals, and these individuals of different sexes, though perfect in all the characteristics of the species, yet are in respect of the reproductive power both imperfect, and therefore seek each other, as it were for the purpose of supplying the deficiency. This fact is represented figuratively in the "Banquet" of Plato by the fable of the two halves of a human body.

CHAPTER II.

OF THE SEXUAL ORGANS.

The sexual organs consist, in both sexes, of a formative organ, the testis or the ovary, and of an efferent organ, the oviduct, or the vas deferens. In the female efferent organ, the ovum in its passage from the ovary generally becomes invested by some new secretions, which are either destined to serve as nutriment, or to form a shell. In many animals one part of the oviduct also forms the receptacle for the ovum during its development, and is called the uterus. A uterus in this sense exists in the viviparous genera of Fishes, Amphibia, and Mammalia, as well as in Man. The secretion of the testes also in its course to the exterior of the body becomes, in many cases, mixed with other secretions, which are poured out by accessory secreting organs connected with the male efferent organ. In those animals in which the two sexes are distinct, but in which impregnation is effected internally, there are superadded at the orifice of the efferent apparatus the organs of sexual connection. The essential sexual organs, however, which are universally present, are the formative organ and the efferent apparatus. The sexual organs of both sexes present two perfectly distinct types, which are characterised by the relation which the formative and efferent organs bear to each other. In one type the efferent organ has the place of a true efferent duct, its walls being continuous with those of the cavities of the formative organ; in the other, the two essential parts of the sexual organs are wholly unconnected, and the ovum, or semen, first makes its way through the parietes of the formative organ into the abdominal cavity, and escapes thence by a special canal. The product of the formative organ may in this case either fall free into the abdominal cavity before making its way out by the efferent canal, or it may be at once received from the ovary or testis into the open end of the tube which is in the neighbourhood.

CHAPTER III.

OF THE UNIMPREGNATED OVUM.

Our knowledge concerning the unimpregnated ovum has been brought to its present state by the labours of modern anatomists, particularly by the exertions of Purkinje, Von Baer, R. Wagner, Coste and Valentin. So successful has been their study of this subject, that in it, as in all the most perfect parts of science, the numerous individual facts can now be referred to simple laws.[*]

In many invertebrate animals, the ova are developed in the interior of cæcal tubes, in which they are not surrounded on all sides by organised tissues, so as to be separated from each other; but in many other of the Invertebrata, and in all the Vertebrata, they are formed within the cells of the ovary. These cells are invested singly by numerous blood-vessels, and are united together by a fibrous substance of a greater or less degree of firmness, called the *stroma*. When the ova lie in insulated cavities of the ovary, the wall of these cavities, formed of the condensed stroma, is called the capsule or *theca*. The following essential parts may be distinguished in the ova of invertebrate animals, fishes, Amphibia, reptiles, and birds,—even in those of the smallest size:

1. The capsule of the ovum, *ovicapsule*, which is in some cases, as in many Invertebrata, insulated from the proper tissue of the ovary, and may even escape with the ovum; but which in other instances, as in the oviparous Vertebrata, coalesces with the theca of the ovary, forming there what is termed the *calyx*. On the side directed from the ovary the calyx is often thin, but thicker on the side next to the ovum, to which it is connected merely by a pedicle. The thin side of the calyx in the ovary of the bird often presents a white band of an arched form, and distinguished from the rest of the calyx by the absence of blood-vessels. This band, the *stigma*, indicates the situation at which the dehiscence of the calyx will subsequently take place to allow the escape of the ovum. Schwann has observed a circumstance which is worthy of remark, as aiding in identifying the capsule of the ovum of different classes,—namely, that a stratum of epithelium cells exists on the inner surface of the ovicapsule in fishes, and also on the inner surface of the *Graafian vesicles* or capsules of the ova of Mammalia. Both Jones and Barry, with justice, regard the ovicapsules of oviparous animals as identical with the Graafian follicles of Mammalia.

2. Within the ovicapsule lies the *yolk*, surrounded by the *vitelline membrane*. This membrane is at first in close contact with the capsule, but subsequently becomes separated from it in many animals by a tolerably large interval. The granules of the yolk are found by Schwann to be cells containing a finely granular matter and oil globules.

3. In the substance of the yolk is imbedded the *vesicle of Purkinje*, or vesicula germinativa. This vesicle is of greatest relative size in the smallest ova, and is in them surrounded closely by the yolk, nearly in the centre of which it lies. During the development of the ovum, the germinal vesicle increases in size much less rapidly than the yolk, and comes to be placed near to its surface. Ovula and germinal vesicles can frequently be detected in the ovaries of the fully developed embryo.

4. The germinal vesicle contains a transparent fluid, and in addition to this, the *germinal spot*, macula germinativa, or nucleus germinativus of R. Wagner. This

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[*] The following are the most important works on this subject:—Purkinje, Symbolæ ad ovi avium historiam ante incubationem, Lips. 1830; and Encyclop. Wörterbuch der medic. Wissensch. Art. Ei. Von Baer, De ovi mammalium et hominis genesi, Lips. 1827. Coste, Recherches sur la géneration des Mammifères, Paris, 1834. Bernhardt (et Valentin), Symbolæ ad ovi mammalium historiam ante impraegnationem, Vratislav, 1834. Valentin. Entwickelungs-geschichte, Berlin, 1835. R. Wagner, Müller's Archiv. 1835, p. 373; Prodromus historiæ generationis hominis atque mammalium, Lips. 1836; Abhandl. der K. Baiersch. Acad. 1837, p. 2; and Lehrbuch der Physiologie, Icones Physiologicæ, Leipz. 1839. Krause in Müller's Archiv. 1837, p. 26. Carus, ibid. 1837, p. 442. Jones, London Med. Gazette, 1838, p. 680. Schwann, Mikroskop. Untersuch. Barry, Philos. Transact. 1838 [and 1839]; and Edinburgh Philos. Journal, 1839. The best figures of the ova of Invertebrata given by the older writers are those of Poli, Goeze, Della Chiaje, and O. Fr. Müller. The ova of fishes had been best shown by Cavolini, Erzeugung der Fische und Krebse, tab. i. fig. 4; and Sonnini, Hist. Nat. des Poissons, t. ii. tab. iii. fig. 4. The structure of the ova is correctly indicated, though it was not understood by these writers.

germinal spot consists of one or more somewhat opaque corpuscles, and is possibly the analogue of the nucleus of formative cells. It is simple in the germinal vesicle of the human subject, of Mammalia, birds, reptiles, and many Invertebrata, and is recognisable even in the ova which are least advanced in development. In Amphibia, the osseous fishes, and several invertebrate animals, the germinal spot is multiple. As the ova advance in development granular matter is deposited on the inner surface of the germinal vesicle, and renders the germinal spot or spots indistinct, and sometimes even invisible. In some of the Invertebrata the germinal spot itself seemed to Wagner to have a special investing membrane.

The ova of mammalia and the human subject find the nutriment necessary for the development of the embryo in the uterus. Hence the extremely small quantity of yolk with which they leave the ovary, and their minute size; their diameter, in their most perfect condition, being scarcely so much as one-tenth of a line. In their relation to the ovary, also, they differ in many particulars from the ova of oviparous animals. Owing to their extreme minuteness, the ovula of man and mammiferous animals for a long time escaped observation. Prevost and Dumas had remarked, that the ova found in the oviducts of animals, shortly after impregnation had taken place, were much smaller than the follicles of Graaf; and in two instances they actually saw the ovulum within the Graafian follicle, but they did not pursue the subject any farther. The merit of discovering the ovulum of mammiferous animals and man really belongs to Von Baer.

The vesicles or follicles of Graaf, or the ovicapsules which contain the ovula of mammals and the human subject, are connected together by a very firm stroma, which, with them, constitutes the ovary. They are but slightly prominent above the surface of the ovary in most Mammalia, but in the Ornithorynchus are raised on pedicles as in birds. Each capsule is formed of two membranes, the more internal of which is like the ovicapsule of oviparous animals, lined with epithelium (membrana granulosa of Baer). The ovulum occupies only a very small part of the cavity of the Graafian vesicle or capsule, the remainder being filled with an albuminous fluid in which microscopic granules float. In immature capsules the ovulum is proportionally larger and lies more nearly in the centre; while in those which are fully formed it is placed close to the inner wall of the capsule, embedded in a granular zone. In both conditions, however, according to Barry, the ovulum is attached to the parietes of the follicle by peculiar granular bands or *retinacula*. In order to examine an ovulum, one of the Graafian vesicles, it matters not whether it be of small size or arrived at maturity, should be pricked and the contained fluid received upon a piece of glass. The ovulum then being found in the midst of the fluid, by means of a simple lens, should be placed under the compound microscope. Owing to its globular form, however, its structure cannot be seen until it is subjected to gentle pressure under a second thin lamina of glass, or by means of a compressorium.

The external investment of the ovulum is a thick membrane, which, under the microscope appears as a bright ring bounded externally and internally by a dark outline. This membrane is called by Valentin and Bernhardt, *zona pellucida;* by R. Wagner, chorion. The anatomists who have occupied themselves most with the examination of this part of the ovulum, are divided in their opinions respecting its nature. According to Krause, it is composed of an albuminous mass, enclosed in a delicate membrane; while Wagner and Bischoff regard it as a simple tunic, because it tears with a uniform margin. Schwann admits that such is the character of its edge when torn, but nevertheless inclines, as does Dr. Barry* also, to Krause's opinion.

Within this transparent investment lies the yolk, which consists of granules or cells and fat globules. This substance forms a globular mass which is usually in close contact with the inner surface of the investment above described. But sometimes in ova, which have attained the most perfect maturity, an interval can be seen between the yolk and its outer tunic, and this interval is rendered greater by the imbibition of water; so that it would seem probable that the mass of yolk is invested with a special membrane-like layer of granules.

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* According to Dr. Barry, the zona pellucida is a solid transparent membrane. He states, however, that internal to this there is a much thinner membrane (the true membrana vitelli), which exists while the ovum is contained in the ovary but disappears by liquefaction in the Fallopian tube, at the same time that the chorion begins to be formed. See Dr. Barry's Researches on Embryology, 2d series, p. 332, 333, and 339.

For a long period after the existence of the germinal vesicle in the ova of oviparous animals was generally known, it remained undiscovered in the ova of mammiferous animals and man; and it then appeared doubtful, whether the ovula of the latter animals should not be regarded as analogous to the germinal vesicle of the oviparous classes. The germinal vesicle of the ovulum of Mammalia was first discovered by Coste, in 1834, but we owe the most accurate information respecting it to the researches of Valentin and Bernhardt. The vesicle is of largest relative size in the least advanced ovula. Its diameter is about $\frac{1}{60}$ of a line. The germinal vesicle can be seen while yet within the ovulum, if the latter be flattened by cautious pressure; and sometimes the ovulum may by the same means be ruptured, so as to allow the germinal vesicle to escape uninjured. Within the germinal vesicle, and close to its surface, is the germinal spot of Wagner, the diameter of which is no more than $\frac{1}{200}$ or $\frac{1}{300}$ of a line. The germinal spot is somewhat opaque, the rest of the contents of the vesicle transparent.

The discus proligerus does not exist in the ovulum of Mammalia, at least not with its characteristic form. But R. Wagner imagines that its place is here supplied by the continuous layer of granules which surrounds the entire yolk.

According to Carus, all the essential parts of the ovulum can be detected in the ovary of the mature embryo of the human subject, or of mammiferous animals.

CHAPTER IV.

OF THE SEMEN.*

GREAT as are the advances which our knowledge of the ovum and female germ has made during the last few years, they do not surpass those by which our acquaintance with the fecundating fluid of the male has arrived at its present state of perfection. The semen has been made the subject of minute investigation by many anatomists, but with most success by Wagner and Von Siebold.

The ova or germs of the female are formed at a very early period, even in the embryo; but the semen and its essential elements are generally not present until the time of sexual maturity.

The semen of animals is a thick white or yellowish white fluid, having a peculiar penetrating smell. It becomes more transparent when exposed to the air, and is coagulated by alcohol; but its chemical properties are, with reference to the theory of generation, less important than its vital endowments. (See *Berzelius, Thierchemie.*) It is composed of three distinct elements, a fluid, granules, and animalcules—the *spermatozoa.* These animalcules are found both in the vas deferens and in the vesiculæ seminales. The fluid of the semen cannot be obtained separate from its other components, and consequently its peculiar properties cannot be ascertained. The granules of the semen are described by Wagner as round bodies finely granulated on their surface, and measuring from $\frac{1}{300}$ to $\frac{1}{400}$ of a line in diameter; they must not be confounded with the particles of epithelium which are sometimes mixed with the semen. The spermatozoa which were discovered by a student at Leyden, named Ham, and first described by Leeuwenhoek, have different forms not only in different classes of animals, but also in different families, genera and species. Their most remarkable varieties in the vertebrata have been investigated and described by Wagner; in the invertebrata, by Von Siebold.

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* *Bibliography.*—Leeuwenhoek, Anatomia seu interioria rerum. Lugd. Bat. 1687. Arcana naturæ. Delphis, 1695. Epistolæ physiologicæ. Delphis, 1719. Gleichen, über die Samen und Infusions-thierchen. Nürnberg, 1778. Prevost et Dumas, Ann. des Sc. Nat. t. i. ii. Czermack, Beiträge zur Lehre von den Spermatozoen. Wien. 1833. Treviranus in Tiedemann's Zeitschrift für Physiol. V. pt. 2. Von Siebold in Müller's Archiv. 1836, p. 232, 1837, p. 381. R. Wagner in Abhandl. der K. Baiersch. Acad. 2, 1837, and Müller's Archiv. 1836, p. 225. Valentin, Repertor. 1836, p. 277. Dujardin, Ann. des Sc. Nat. t. viii. 291, 297. Donné, L'institut. 1837, 206. Ehrenberg, Die Infusions-thierchen, p. 464. Valentin, Nov. Act. nat. cur. t. xix. Hallmann, Müller's Archiv. 1840, p. 467.

The spermatozoa of the human subject measure, according to Wagner, from $\frac{1}{50}$ to $\frac{1}{40}$ of a line in length; their oval flattened body from $\frac{1}{600}$ to $\frac{1}{800}$ of a line. The tail is at its commencement so thick that its two borders can be distinguished; but towards its free extremity it becomes of extreme tenuity. The spermatozoa of most Mammalia are of the same form as those of the human subject, but are generally larger, especially in the smallest animals, for example, in those of the mouse kind; their length in the rat being, according to Wagner, $\frac{1}{12}$th of a line. In monkeys they have great similarity to those of the human semen.

With the organisation of the spermatozoa we are at present quite unacquainted, and it has hitherto appeared doubtful whether they have an animal organisation. Henle and Schwann perceived a spot in the body of the human spermatic animalcule, which called to mind the sucker of the Cercariæ; but this might have been a part, bearing the same relation to the body of the animalcule as the nucleus does to the cell. In many spermatozoa there is sometimes a small knot in the middle of the tail or towards its end; I observed this knot in the spermatozoa of Petromyzon marinus, but in most of the animalcules it was absent. Similar knots in the course of the caudal filament have been observed by Meyen in the spermatozoa of plants; for example, in those of Charæ.*

The movements of the spermatozoa resemble in their characters the voluntary motions of animals. They consist in lashing, undulating, and vibrating motions of the tail. Those with the spirally-twisted body have a corresponding spiral twisting motion. (See *Wagner's Physiologie*, p. 15.) In order to see their motions well, it is necessary to dilute the semen with serum of blood. In many instances these motions of the spermatozoa continue during many hours after the death of the animal from which they are taken, and the mode of its death has no influence upon them.

The mode of development of the spermatozoa has been discovered by Wagner. During the winter the fluid of the testes of passerine birds contain merely small granules. In the spring there are granules of various forms, and, mingled with them, spermatozoa united in fasciculi. These fasciculi of spermatozoa are at first enclosed in very delicate vesicles or cells, in which they lie, all with their spirally-twisted anterior portions or bodies together at one end of the fasciculus, and with their caudal extremities at the other end. These animalcules in the testis present no motion, but in the vas deferens the individual animalcules are free and in motion. The semen of the testis contains, besides small granular globules, large vesicles, including one or two granular globules, and similar larger vesicular bodies, enclosing several such granulated globules. These vesicles have a close relation to the development of the spermatozoa; for Wagner observed that a finely granulated matter was at length deposited between the globules which they contain; that these globules then disappeared; and that a linear arrangement of granules began to be visible, which at length assumed distinctly the form of the fasciculi of spermatozoa above described. The process of development of the spermatic animalcules is the same, according to Wagner's observation, in frogs and Mammalia. In birds the spermatozoa are produced anew each year, and disappear in the autumn. In Mammalia their formation commences at an early age; in rabbits their development is completed, according to Wagner, at the third month after birth; in cats and dogs it is effected much later, and in the human subject it does not take place until the period of puberty. These important observations have been confirmed by Von Siebold, (*Müller's Archiv.* 1839, p. 436,) and Valentin, (*Repertorium*, 1837, p. 143,) and by Dr. Hallmann, *Müller's Archiv.* 1840, p. 467,) who has observed the development of the spermatozoa in the cells of the testis of the ray.

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* The spermatozoa which present the most evident signs of organisation are those of the bear, described by Valentin, (Nov. Act. Nat. Cur. t. xix.) They appeared to him to have a mouth, an anus, and stomachs or a convoluted intestine.

It is yet a question which cannot be answered with certainty, whether the spermatozoa are independent parasitic animals, or merely animated particles of the organism in which they exist. Ehrenberg is inclined to regard the spermatozoa as distinct animals, and places them with the Cercaria in the class of the true Entozoa. Treviranus, on the contrary, adopts the opposite view, and compares the spermatozoa to the grains of pollen. The absence of spermatozoa in the semen of some animals, and the existence of perfectly organised animals in the seminal reservoirs of the Sepia,* are circumstances favourable to the former opinion: while, on the other hand, the absence of structure, such as other individual animal organisms possess, in the body of the spermatozoa; their presence in nearly all animals, and reappearance in almost the same form in the male generative organs of some plants; the fact of their being developed in a uniform manner from cells, and not from other spermatozoa; and the analogy which may be perceived to subsist between them and other organic cells, particularly the cells bearing cilia; are all circumstances opposed to that opinion. The spermatozoa resemble the cells bearing cilia, in their motions continuing after they are separated from the parent organism; and their caudal filaments may be compared to the cilia, while the nucleus of their body finds its analogue in the nucleus of the ciliated cells. In the character of their movements, however, the spermatozoa do not at all resemble the cilia, but present much more resemblance to animals moving voluntarily.

The most weighty argument against the special and individual animality of the spermatozoa is their close connection with the fecundating property of the semen. Not only are they absent from the semen of many animals, and particularly of birds, except at the pairing time, but their development is imperfect in hybrid animals, which are generally incapable of reproducing their kind, or at most pair with individuals of one of the unmixed species, and produce forms which then return to the original fixed type. Hebenstreit, Bonnet, and Gleichen, all failed to detect spermatozoa in the semen of the male mule. More recently Prevost, and Dumas, (*Annal. des Sc. Nat.* i. p. 183,) and R. Wagner, have examined the seminal fluid of hybrid birds, and have found the spermatozoa either absent or imperfectly developed. This fact of the spermatozoa being imperfectly developed in such animals is most important.

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* See the account of these bodies given by Carus in the Nov. Act. Nat. Cur. t. xix. p. 1; also Philippi in Müller's Archiv. 1839. [Carus imagined that these bodies were distinct animals, and described their large intestine, small intestine, stomach, proventriculus, and œsophagus. It has, however, been clearly shown by Von Siebold (Beiträge zur Naturgeschichte der Wirbellosen Thiere, Dantzig 1839), that Carus was in error, and that the original description given by Needham was, as far as it went, perfectly correct. They are really capsules containing the semen of the Cephalopod. The spongy mass, believed by the English microscopist to contain the semen, is, according to Siebold, composed almost entirely of spermatozoa, which have an oblong body, and long thread-like tail. Needham's observations were made on the Loligo; Siebold's on the Cyclops. Their views have been confirmed by Peters (Müller's Archiv. 1840, p. 98), and by Mr. Owen in his Lectures at the Royal College of Surgeons, 1840. (See Lancet, May 14, 1840).]

Spermatozoa are sometimes met with in the male sexual organs of plants, but much more rarely than in animals. It being very difficult to distinguish the motion which the contents of the pollen grains of the higher orders of plants present from the molecular motion of Brown, we shall notice merely the spermatozoa of the Cryptogamic plants.

CHAPTER V.

OF PUBERTY, SEXUAL INTERCOURSE, AND FECUNDATION.

I. *Puberty.*—The period of puberty, the commencement of that part of life which is distinguished by the capability of propagating the species, does not occur exactly simultaneously in the two sexes; and still greater variety in this respect is caused by differences of nation and climate. Puberty declares itself in the female sex of our climate about the 13th, 14th, or 15th year, and is indicated by the occurrence of menstruation. In the male sex puberty commences about the 14th, 15th, or 16th year, and is attended with the secretion of semen, and with the occurrence of discharges of that fluid. In hot climates the body undergoes the changes of puberty earlier than in cold climates. It is stated that in the hot regions of Africa they take place in the female sex as early as the 8th year, and during the 9th year in Persia. Young Jewesses are also said to menstruate earlier than other females in our own country. The capability of reproduction generally ceases in the female sex, together with the function of menstruation, between the 45th and 50th years. The duration of the reproductive power in man cannot be so exactly defined; in general, it continues longer than in woman, and not unfrequently very old men manifest a remarkable degree of virile power.

The changes in the system which characterise the period of puberty are partly local, affecting the generative organs, and partly of a general nature. The local changes consist in the growth of hair on the pubes in both sexes; in the menstruation of the female; in the copious formation of semen, and occurrence of erection in the male; and in the enlargement of the breasts in the female sex. The general changes of the system affect principally the respiratory and vocal apparatus, the entire form of the body and the physiognomy, the character of the mind, and the feelings relating to the sexes. The respiratory organs acquire an increase of volume at the age of puberty, especially in the male sex; and the vocal apparatus undergoes those changes of dimension and acoustic properties which have been described in another part of this work. The whole body attains its most perfect form; while the features receive their stamp of individuality, and present signs serving to express the passions, though they are not yet so strongly marked as in many adults. Sexual ideas arise instinctively and obscurely in the mind, and set in action the creative power of the imagination; but, at the same time, by their influence on the whole mind, call into play the noblest mental faculties, so as to elevate and adorn the feeling of love.

Menstruation is the periodical discharge from the female generative organs of a bloody fluid poured out by the inner surface of the uterus. The first discharge is usually preceded and accompanied by some symptoms of general disturbance of the system, namely, by abdominal congestion, pain in the loins, and a sense of fatigue in the lower limbs. Its periodical return is also attended in most women by abnormal symptoms, which are different in different individuals. The menstrual periods occur usually at intervals of a solar month; their duration being from three to six days. In some women the intervals are as short as three weeks, or even less; while in others they are longer than a month. Aristotle (*Hist. Anim.* 7, 2,) made the extraordinary statement that menstruation rarely occurs every month, but in most women only every three months.

The menstrual discharge differs from ordinary blood in no other respect than that of containing only a very small quantity of fibrine, or none at all. (*Lavagna, Meckel's Archiv.* 1818, bd. iv. p. 151.) The blood corpuscules exist in it in their natural state.

Menstruation does not occur in pregnant women, nor in most cases in those who are suckling. But in rare instances it continues even during pregnancy.

Menstruation, in the strict sense, is peculiar to the human female. A kind of menstrual discharge was occasionally noticed by Rengger in the female of Cebus Azarræ; but this did not occur at regular periods. It was small in quantity, continued two or three days, and returned after intervals of three, six, or even ten weeks. This sign of maturity did not show itself until the end of the second year.* Geoffroy St. Hilaire, and Fr. Cuvier,† have observed many facts of a similar kind among the monkey tribe. They noticed discharge of blood with enlargement of the sexual organs in Cercopithecus, Macacus, and Cynocephalus; but they maintain that these appearances were coincident with the monthly heat. During the periodical sexual heat in other animals also, as the horse and dog, there is sometimes a discharge of blood. But the menstruation of the human female is a phenomenon of a totally different nature, and has no connection with sexual excitement.

We are quite ignorant of the cause of menstruation and its periodical return. The notion of the ancients that it cleansed the body from noxious matters is evidently erroneous. The opinion, also, that its office is to relieve the uterus of the blood which during pregnancy would nourish the embryo, is unsatisfactory, since the small quantity of blood lost in menstruation does not correspond with the amount of nutriment which the fœtus derives from the mother. More probability attaches to the view that the human female is preserved from too great sexual excitement by the menstrual flux.

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* Rengger, Naturgeschichte der Säugethiere von Paraguay. Basel. 1830, p. 49.

† See their work, Hist. Nat. des Mammifères. See also Ehrenberg, Abhandl. der Acad. zu Berlin, 1833, pp. 351-358, on the occurrence of menstruation in the monkey tribe; and Numan, Froriep's Notizen, p. 150, on menstruation in animals generally.

But it is still more probable that menstruation is the result of a periodical regeneration,—a kind of moulting of the female generative organs, attended perhaps with the formation of a new epithelium. The periodicity of the phenomenon is not connected with the changes of the moon, but with some condition of the organism itself; like other periodical actions or functions, it has an internal cause. The variations of the light afforded by the moon bear no constant relation to the periods of menstruation; on the contrary, different females are menstruating on every day of the month. The intervals of menstruation also, even when most regular, are not lunar but solar months; and they are very different in different women, in consequence of the various states of their system, and quite independently of external causes.

In the male sex the tendency to periodicity is manifested only in the turgescence of the genitals, and greater excitability and potency of the spinal cord and nerves engaged in the generative function; a state which is terminated, as it were by a crisis, in the act of coïtus, or in the involuntary emission of semen. Women are much less, or perhaps not at all, subject to such periodical sexual excitement. The periodical heat occurs in the most marked degree in animals. In many of them it happens during the spring, as in most birds, reptiles, and Amphibia, in many fishes, and also in many mammals, as the rodents, moles, and horses. In other animals, as several fishes, birds, Amphibia, and Mammalia, the summer is the season of sexual heat; while in others again, as many ruminants, it occurs in the autumn; and in others, as dogs, cats, and other carnivorous animals, in the winter. (See the more detailed account in *Burdach's Physiologie*, bd. i. p. 381.) In tame animals the periodical sexual excitement is manifested with much less intensity than in the same animals in their wild state; and in many, as the elephant, sexual union never takes place while they are in confinement.

All the phenomena connected with the sexes which animals present, are dependent on the formative generative organs, the ovaries and testes, and on the influence which they exert on the rest of the organism. Not merely does castration during youth for the most part prevent the development of the sexual feelings and emotions; but even when performed at adult age that operation destroys nearly entirely the sexual excitability. Sir A. Cooper (on the structure and diseases of the testis, pp. 53, 54,) had the opportunity of knowing during twenty-nine years a man both of whose testes had been extirpated. The operation was performed in 1801. "For nearly the first twelve months, he stated, that he had emissions *in coïtu* or that he had sensations of emission. That then he had erections and coïtus at distant intervals, but without the sensation of emission. After two years he had erections very rarely and very imperfectly, and they generally immediately ceased under an attempt at coïtus. Ten years after the operation, he said he had, during the past year, been once connected." In 1829 he stated, "that for four years he had seldom any erection, and then that it was imperfect. That he had for many years only a few times attempted coïtus, but unsuccessfully; that he had once or twice dreams of desire and a sensation of emission, but without the slightest appearance of it."

II. *The act of sexual union.*—The act of sexual union, as regards the male sex, consists of erection and the ejaculation of semen. Erection is the result of the arrest of blood in the corpora cavernosa of the penis, effected most probably, as Krause (*Müller's Archiv.* 1837,) shows, by the action of the musculi erectores penis, which compress the deep veins of the organ as they issue from the corpora cavernosa, though they can exert no influence on the vena dorsalis. In the horse the veins of the corpora cavernosa give off such numerous communicating branches in different directions, that it is more difficult to explain there the act of erection.* The part played by the arteriæ helicinæ in this act is not known; they cannot, however, be its sole cause, since in several animals, as the elephant, they do not exist, and even in the horse have quite a rudimentary form. It is in these animals that the muscle-like bands, passing between the veins of the corpora cavernosa, which were first observed by Hunter, are most highly developed. The remote source of the power of erection is the spinal cord; and hence the loss of this power in cases of Neuralgia dorsalis or Tabes dorsalis.

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* On the cause of erection in the horse, consult Guenther, Untersuchungen und Erfahrungen im Gebiete der Anatomie, Physiologie und Thier-arzneikunde. Hannover, 1837.

The emission or ejaculation of the semen is a reflex action excited by irritation of the sensitive nerves of the penis. The act of ejaculation is itself the result of two movements; namely, of the persistent contraction of the organic muscular fibres of the vesiculæ seminales, and of the repeated periodical contraction of the animal muscular fibres of the ejaculator seminis and other perinæal muscles. Sudden irritation and injury of the medulla spinalis gives rise to emission of semen, which is then not necessarily attended by erection. Discharge of semen is an ordinary phenomenon in decapitated criminals. That the vesiculæ seminales are really receptacles of semen is beyond a doubt, since spermatic animalcules have been discovered in their contents in the human subject after death. They are, therefore, not mere secreting organs as Hunter supposed. (*Hunter's Works* [*Palmer's edition*], vol. iv. p. 20.) Hunter, however, proved by a series of observations, that when one testicle is extirpated, the vesicula seminalis of that side does not undergo diminution in size; and his view respecting the office of the vesiculæ was correct, so far as regards their secreting a mucous fluid. In the act of coition, however, the semen comes directly from the vesiculæ seminales, and not from the testes. It is, moreover, mixed in the urethra with the secretion of Cowper's glands, and with that of the prostatic gland, of the nature of which we are quite ignorant.

In both sexes the act of coition is attended with pleasurable sensations, but their respective share in the act itself is very different. In the female there is no expenditure of the nervous power in the production of erection, no energetic rhythmic muscular contractions when the venereal excitement has reached its height, and no emission of semen; but merely an increased secretion of mucus from the mucous follicles of the vagina, excited by the impressions on the sensitive nerves of the female sexual organs, and serving to lubricate the passage. The man feels exhausted after the act; the woman does not. It appears, therefore, that the nervous excitement and actions of the male during the act of coition, attain, in a short period, a great degree of intensity, and are as rapidly depressed, while there is no evidence that such is the case in the woman. The clitoris, which is known to be the part most susceptible of the pleasurable sensations in the female, is not, like the penis of the male, rendered by friction the seat of intense sensation and nervous excitement during coition, and hence its excitability is found not to be wholly exhausted after the act is completed. We are, therefore, justified in concluding that the sensitive excitement of the woman is neither so rapidly rendered intense, nor so rapidly depressed, as that of the man; and this conclusion accords with the fact, that women bear frequent sexual intercourse better than men, and are much less frequently affected with Tabes dorsalis, in consequence of sexual excess. The clitoris, though agreeing with the penis in its mode of development, yet differs from it essentially in its functions, since it is generally incapable of true erection. In the genus of monkeys, Ateles, the clitoris is normally of extraordinary length, and this circumstance has given foundation to the accounts related of the structure and habits of some female monkeys. The clitoris of the females of the genus Ateles has very large corpora cavernosa, in which, however, I have found merely fat; while the sensitive nerves of the penis, the nervi dorsales, were very large.* This large size of the clitoris is peculiar to the genus Ateles; in other genera of monkeys the organ presents nothing unusual.

III. *Separation of the ova from the ovary, and their reception into the Fallopian tubes.*—In oviparous animals the separation of ova from the ovarium may take place either independently of impregnation by the male, or as the result of that act. In the Amphibia, the ova of which are impregnated out of the body of the female, for example, in frogs, the ova have separated from the ovary, and have accumulated in the oviduct long before the time of fructification. The ova of the female frog having accumulated in the oviduct, and distended it to a considerable size, are expelled from it by the action of its walls during the excitement of copulation, and are immediately impregnated by the male, who sits on the back of the female firmly embracing her.

In fishes, also, the ova seem to separate from the ovaries before fecundation. For in the majority of fishes there is no sexual union. The male and female, under the venereal excitement, accompany each other through the water, and the ova being deposited by the female are fecundated by the semen which the male emits. There are some fishes, however, as the Blennius viviparus and other viviparous fishes, in which internal impregnation is effected, either by the semen emitted by the male finding its way with the water into the internal generative organs of the female, or by an actual act of copulation as in the sharks and rays.

Birds, also, which begin to lay their eggs after copulation and impregnation, continue to lay them when they are kept quite separate from the male bird; and here, also, the ova evidently separate from the ovary independently of impregnation. The same is the case with some insects, as, for example, butterflies; for they also deposit mature ova when they have been kept isolated from the male from the time of their entrance into the chrysalis state.

In Mammalia, on the contrary, the separation of the ova from the ovary seems to be dependent on the act of impregnation. It has, it is true, been stated, that cicatrices of the ovaries, resulting from the escape of ova, have been seen in the bodies of virgins (*Home, Philos. Transact.*); but that is certainly not an ordinary occurrence. Usually, it is only after a successful union of the sexes, that one or more Graafian vesicles are found turgid. At a somewhat later period, after coition has taken place, the turgid and vascular vesicle of De Graaf bursts, and the ovulum is received into the Fallopian tube. These results of a fruitful union of the sexes, the change in the condition of the ovary, the dehiscence of the Graafian follicle and escape of the ovulum, are now known to be consequences of the direct action of the semen on the ovary itself, and not of its action merely on the external generative organs. For Professor Bischoff and Dr. Barry have made the important discovery, that the semen of male mammiferous animals which have been induced to copulate, is really conducted through the entire length of the Fallopian tube to the ovary.

The mode in which the ova, unimpregnated or impregnated, are transferred from the ovary to the Fallopian tube or oviduct is far from being accurately known.

In Mammalia and birds the proximity of the ovary to the infundibulum of the Fallopian tube must, to a certain extent, facilitate the entrance of the ovum into the latter; but even here there is a phenomenon, as yet unexplained, in the Fallopian tube applying its infundibulum, or fimbriæ, at the time of impregnation, not merely to the ovary, but exactly to that part of it at which there is an ovicapsule on the point of bursting. This erectile turgescence of the Fallopian tube, and its close application to the ovary, have been many times observed in mammiferous animals,—namely, by De Graaf, Kuhlemann, Haighton, Cruikshank, Von Baer, and Wagner. The phenomenon continues during the first few days after coition has taken place. Von Baer observed it in pigs and sheep as late as the fourth week, while Wagner found that it ceased in pigs about the eighth or tenth day.

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* See Fugger, De Singulari Clitoridis in Simiis Generis Ateles Magnitudine et Conformatione. Berol. 1835.

The changes which precede the expulsion of the ovum from its capsule, and which the capsule afterwards undergoes, are the following:—Both in oviparous animals and in Mammalia the posterior part of the capsule swells before the escape of the ovum; but in Mammalia this tumefaction is much greater than in other animals, and the swollen capsule appears very vascular. Even before the ovulum has left its cavity, the capsule becomes in a great part filled with a brownish-yellow substance. In consequence of this change the contents of the capsule are protruded against its outer wall, which has become thinner, and now projects with the ovulum beneath it in a hemispherical form above the surface of the ovary and thickened follicle. An aperture, the stigma, is then formed at the most prominent point. Immediately after the escape of the ovulum the cavity of the follicle, or Graafian vesicle, appears very small; in a short time it becomes quite filled with a granular mass, and a kind of wart is developed in the situation of the former opening. This wart afterwards disappears, and then the altered follicle remains with the form of the round corpus luteum. In oviparous animals the calyx gradually diminishes in size after the escape of the ovum, and is retracted into the mass of the ovary and absorbed.

According to Dr. Barry, (*Phil. Trans.* 1839. Pt. ii. p. 317,) the corpus luteum of mammiferous animals is developed in the vascular covering of the ovisac, or external tunic of the Graafian vesicle. Dr. R. Lee, (*Med. Chir. Trans.* vol. xxii. p. 329,) on the contrary, supposes that it is formed externally to both coats of the vesicle. Dr. Montgomery (*On the Signs of Pregnancy*, p. 216) and Dr. Patterson (*Edinb. Med. and Surg. Journal*, Nos. 142 and 145), again, state as the result of their observations, that the substance of the corpus luteum is deposited between the coats of the follicle. The true corpus luteum appears never to be produced except as the result of conception. False corpora lutea, on the contrary, are frequently met with. They generally, according to Dr. Montgomery, appear to be formed by an extravasation within the Graafian vesicle. A thickened state of the coats of the vesicle, which ensues in advanced age, sometimes simulates a corpus luteum. False cicatrices of a vesicle have an irregular form, and want the small round opening which is the result of conception. In the ovaria of women who had died during menstruation, Dr. Lee saw other appearances which might have been mistaken for corpora lutea. The Fallopian tubes were red and turgid; the peritoneal coat of one ovary was perforated by a small circular opening, around which the surface of the ovary was elevated, and of a bright red colour, and the opening sometimes communicated with a cavity; but the distinctive characters of the corpus luteum were wanting.

IV. *Fecundation.*—The semen might be supposed to effect fecundation in different ways. Its immediate action might be on the organism of the female, the fecundation of the ovum being a secondary and indirect result of this action; or it might be exerted directly upon the ovum itself. In the former case, the semen could be conceived to act as a stimulant of the female genitals, producing a state of excitement of which fecundation is the effect; or it might be absorbed into the blood of the female, which would explain not only the changes that take place in the ovary, but also the more general results of fecundation. There have, indeed, been writers who, resting on these theories, have imagined the possibility of fecundation being effected in other than the ordinary way, by means of semen infused into the blood. Observations, however, have shown that the fecundation, following union of the sexes, results from the direct action of the semen upon the ovum. This is proved partly by the experiments of Haighton, (*Phil. Trans.*

1797,) in which ligature of one Fallopian tube before copulation prevented the impregnation of the ovary of that side, while fecundation always took place in the ovary of the opposite side on which the Fallopian tube was left free; and partly by the cases in which, either artificially or naturally, impregnation is effected quite independently of the female organs of generation.

It is equally certain that fecundation does not depend on any influence of the entire male organism, but on the semen alone. This, indeed, was proved long since by experiments of Spallanzani and Rossi, who found that semen of a dog, introduced by means of a syringe into the generative organs of a bitch, effected impregnation. There can, therefore, be no doubt that the essential cause of fecundation, wherever it takes place, is not any influence of the male organism upon the female, but the action of the semen itself upon the female germ.

Two views have been taken of the mode of action of the semen on the ovum. Some physiologists have believed it to be immediate, while others have supposed it to take place through the intervention of a peculiar emanation, the aura seminalis. The falsity of the latter opinion is sufficiently proved by Spallanzani's observations, already referred to, which show the necessity of absolute contact of the semen with the ova of frogs, for producing fecundation. Where the ova were suspended above the semen, and very close to its surface, no fecundation took place; while semen, diluted in the proportion of three grains to eighteen ounces of water, was efficient for impregnating by contact. Spallanzani found a drop of this fluid adequate to impregnate ova. (*See Spallanzani, Expériences pour servir à l'Histoire de la Génération. Genève,* 1786.)

But it is not merely in Amphibia and fishes that the contact of the semen with the ova is thus necessary for fecundation; the fact of the semen being conveyed in Mammalia from the uterus along the Fallopian tubes, even to the ovary, proves that the same condition obtains in all animals. The semen passes into the uterus either soon after or during the act of copulation. Leeuwenhoek, on several occasions, detected spermatozoa in the uterus of mammiferous animals, which had recently had sexual union. Prevost and Dumas (*Annal. des Sc. Nat.* tom. iii. p. 119,) discovered them in the uterus twenty-four hours after the act of copulation, and on the third and fourth days in the Fallopian tubes. Bischoff's observations (*Wagner's Physiologie,* p. 49,) are still more conclusive. In a bitch which had had coition with a dog nineteen hours before, and again half an hour before it was killed and examined, he found spermatic animacules upon and between the fimbriæ of the tubes, and in the sac or peritoneal capsule round the ovary and even upon this organ itself. Wagner, in the same year, (1838,) relates a similar observation made by himself on a bitch, in which the examination was instituted forty-eight hours after coition had taken place: he detected the seminal animalcules not merely in the uterus and Fallopian tubes, among the fimbriæ, and close to the ovary, in which there were three Graafian vesicles ready to burst. In Mammalia, therefore, as well as in other animals, it is an ascertained fact, that the semen and ovum are brought into immediate contact.*

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* Dr. Barry's observations were made on the rabbit. In seventeen out of nineteen instances he was unable to discover spermatozoa in the fluid collected from the surface of the ovary. On one occasion he found a single spermatozoon, which was dead, while the ova had escaped. On a second occasion he found, twenty-four hours post coïtum, several spermatozoa on the ovary. Some of these animalcules were alive and

The situation in which the impregnation of the ovum takes place, is very different in different animals. We have already seen that the ovum may be separated from the ovary before as well as subsequent to impregnation. Hence it follows that impregnation may take place in three situations.

a. *Impregnation external to the body of the female.*—It has already been mentioned, that this is the mode of impregnation in most Amphibia and fishes.

b. *Impregnation of the ovum while still in the ovary.*—This is the place of impregnation, at all events, in man and mammiferous animals. In all cases of extra-uterine pregnancy, in which the ovum is developed in the ovary itself, or escaping into the abdominal cavity is developed there, it cannot be doubted that the ovum was in those instances impregnated in the ovary; but the fact of Bischoff and Barry having traced the spermatozoa as far as the ovary, proves that impregnation is always effected in that situation in Mammalia. The mode in which the semen is conducted so far through the female generative organs, is no longer a problem requiring solution; for the discovery of the ciliary motion affords a solution of it. It is difficult, however, to explain the occurrence of fecundation when the hymen is still perfect, or when the penis is very short or affected with congenital hypospadia. How fecundation is attained in these cases, which are rare, is quite a mystery. (*See the remarks on cases of this kind in Burdach's Physiology,* bd. i. 528.) I must, however, remark, that it is only in the first of them,—that of the persistent hymen,—that the possibility of fecundation appears to me to be absolutely certain. In other cases, all the conditions for absolute proof cannot possibly be fulfilled; for, that the impregnation of a female was effected by a hypospadiac and not by another man, must always be a mere matter of faith.

Of the intimate changes on which fecundation depends, we are yet wholly ignorant; and up to the present time it was the less possible for us to become acquainted with them, since we were uncertain even as to the situation in which the process took place. The principal question which it is desirable to decide with regard to the nature of the fecundating process respects the part which the spermatozoa play therein. Do they serve merely to increase the sphere of action of the fertilising matter, as insects, carrying abroad the pollen, aid in the fecundation of plants, or do they themselves contain the essential fertilising principle? The observation of R. Wagner, that the spermatozoa suffer a change of form in hybrid animals is in favour of the latter view. The spermatic animalcules, however, certainly bear no intimate relation to the germinal vesicle; for in the ova of oviparous animals the germinal vesicle disappears at the time of their discharge from the ovary when they are yet unimpregnated. Equally certain is it that the spermatozoa do not become the future embryos. For the germinal disk appears perfectly unchanged after fecundation, and the development of the embryo by the growth of the germinal disk to form the

active, though not in locomotion; others were dead. There was no enlargement of the Graafian vesicles, nor a high degree of vascularity of any of the parts. Phil. Trans. 1839, pt. ii. p. 315.

germinal membrane, and the subsequent changes of organisation, can be accurately traced. Vegetable physiology has gone a step further than animal physiology in the elucidation of the act of fecundation; hence it is important for us to examine this process as it occurs in the vegetable kingdom.

The parts of plants which have hitherto been regarded as the male sexual organs, are the anthers. The pollen grains contained within the anthers enclose a semi-fluid matter, the fovilla, composed in great part of minute globules, the nature of whose motions is yet a subject of disputation. (See Meyen, op. cit.)

The pistil is usually regarded as the female part of the flower; its upper part is called the stigma; and its lower part is the ovarium, or germen, in which the ovula are formed long before impregnation. The stigma and ovarium are united by the style. The style is formed internally of cellular tissue, which either occupies the whole thickness of the style as low as the ovarium, or more commonly includes a central cavity, which extends from the stigma to the ovarium, where it divides into as many branches as there are ova. The ovulum has generally two coats, or integuments, the primine and secundine, which enclose the cellular nucleus or perisperm. Both coats of the ovulum are connected with the ovarium through the medium of the funiculus which transmits the vessels that terminate in the primine and secundine. Both these coats also present at another point an opening, the micropyle or foramen, which leads to the internal portion of the ovulum, or the nucleus. In many plants the nucleus projects through the foramen in the form of a conical prominence. In the interior of the nucleus is a cavity, the sac of the embryo, which is formed by a single cell, and is of great importance in the process of fecundation.

At the period of fecundation the anthers of hermaphrodite flowers approach the stigma, and shed their pollen upon it. In plants of which the sexes are distinct the pollen is conveyed to the female ovaria, often from a considerable distance, either by the wind or by insects. The intimate steps of the process of fecundation have been brought to light by modern researches. Amici observed that the pollen grains, when received upon the stigma, emitted tubes. Brogniart traced these elongating tubes into the tissue of the stigma. They are productions of the inner coat of the pollen grain, and increase in length by true vegetative growth, and by the appropriation of nutritive matters which they derive from the stigma. More recently the pollen tubes have been found to extend through the canal of the style, or its cellular tissue to the ovulum, and have been ascertained to enter the foramen or micropyle. The nature of the act of fecundation has thus, by the observations of Robert Brown, Horkel, Schleiden, and Meyen, been fully established in the case of many plants. These observations, however, have led to differences of opinion respecting the sexes of plants. Mirbel regarded the act of fecundation as the engrafting of a male cell upon a female cell. According to Schleiden's observations,* on the contrary, the pollen tube itself becomes the future embryo. He describes the extremity of the pollen tube as entering the foramen of the ovulum, as pushing the embryosac before it, and as becoming imbedded in it. The part thus included in the ovulum, according to Schleiden, becomes separated by a constriction, and detached from the rest of the pollen tube; forms the rudiment of the future embryo, and is the nidus for the development of new cells. According to this description, which is based on numerous observations, the doctrine of the sexes of plants must be entirely reformed, and the parts hitherto regarded as the female sexual organs must be viewed merely as a kind of uterus, in which the embryo is nourished. Other writers, and especially Treviranus and Meyen, support the old theory of the sexuality of plants.

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* Wiegman's Archiv. 1837, t. i. p. 291. Nov. Act. Nat. Cur. t. xix. p. 1.

CHAPTER VI.

THE THEORY OF SEXUAL GENERATION.

a. Casper Fried. Wolff's theory of the fecundation of plants and animals.

THE fundamental notion on which Wolff bases his theory of conception is, that in fructification the vegetation of plants attains its end, and that as soon as flowers are developed at the extremity of the axis of a plant, that part becomes incapable of prolonging the axis by the formation of leaf buds. He then shows that the organs of fructification are merely modified leaves. The calyx of the sunflower, he says, is composed of a number of leaves smaller than the ordinary leaves of the plant, closely aggregated together. The petals, again, are merely leaves, as is evident in the grasses. The corolla of grasses is not distinguished from the calyx (or paleæ), and differs from the ordinary large leaves of the grass in no other respect than the calyx differs from them. The colour of flowers is not essential and often is gradually developed. The flower of Statice has many calyces, of which the most inferior is pale and devoid of colour, the next succeeding more and more inclined to red, and the most superior, like the flower itself, of the deepest red, although its figure is not different from that of the other calyces. The seed-vessels are evidently modified leaves, for, when they are ripe and dehisce, each valve appears as a true leaf. The same is the case with the seeds. As soon as they are put into the ground, their lateral halves, or cotyledons, become transformed into leaves.

Wolff next demonstrates that the modification which leaves undergo in the formation of the flowers is dependent on an arrest of the vegetative process. The leaves which constitute the calyx of the sunflower, are, he observes, scarcely one eighth part so broad as the ordinary leaves of the plant, and are much shorter. The leaves forming the calyx (or bracts) and flower of the grasses are scarcely one-fifth part so long as the perfect leaves. He adds, that the proper leaves of a plant gradually become imperfect as they are nearer to the organs of fructification, and remarks that this is so much the case in the sunflower and many other plants, that it is impossible to say where the ordinary leaves cease and those of the calyx begin. It may be added, that the internodia of the stem are shorter and shorter in proportion as they are nearer to the flowers, and that in the position of the sepals composing the calyx of many plants, the spiral arrangement of the leaves of the stem can still be distinctly traced. The vegetative action, therefore, says Wolff, evidently becomes more imperfect and weaker towards the point of fructification; and it must, at length, entirely cease. This perfect arrest of vegetation takes place in the seeds. The want of nutritive juices is the cause of the arrest of vegetation, as is shown by the withering and fall of the fruit. If a plant which is known to put forth leaves a certain number of times, for instance, six times, before developing the organs of fructification, is set in a very poor soil, not only will its leaves generally become very small and imperfect, but it will scarcely have put forth leaves three times before fructification will take place. If this same plant is placed, not in poor, but in moist and rich soil, its leaves will become larger and more perfectly formed, and instead of developing leaves six times, it will put them forth nine times before it shows the organs of fructification. Moreover, if, while the fructification of a plant is thus delayed by the richness of the soil, it is transplanted to a poor soil, flowers will immediately appear. Lastly, if a plant which has already developed the calyx and rudiments of the corolla and anthers in poor soil, is quickly transplanted to rich soil, the anthers can be seen to become transformed into petals in consequence of the excess of nutriment.

In the next place, Wolff remarks that the first parts of the young plant, developed by the power of the male semen, do not differ from the ordinary leaves of the parent plant. The young plumula, is, like the leaf bud of the parent plant, composed of young leaves. Both, therefore, require for their development the same agency or cause, which was in operation in the old plant when it produced its ordinary leaves. The male semen, or the pollen, must be this cause of vegetation, which was previously deficient; or, in other words, it must be nutriment in its highest perfection. The afflux of the ordinary nutriment of the plant to the extremity of its axis by the ordinary passages, ceases; but the male semen, or pollen, is a kind of nutriment, which, instead of being conveyed through the ordinary channels, is supplied from without to the parts of the plant destined to undergo vegetation.

Wolff explains the phenomenon of conception in animals in the same way. The ovary is the part of the animal organism in which the vegetative action is arrested, and hence it may be compared to the imperfectly developed terminal bud of plants.

b. Critical examination of Wolff's theory.

In Wolff's theory of conception there is much that is perfectly correct, but its main conclusion is erroneous and involves a false view of the nature of semen. It is quite true that fructification is the result of abortive vegetation; but this abortive development is of an extraordinary kind, and cannot be removed by the most perfect nutriment. A deciduous leaf-bud is also abortive in its vegetation, and was so, even before its separation from the parent plant; there are leaf-buds, as we have seen, which consist merely of a single cell, and which, therefore, are quite as simple as the germ formed in fructification; and, nevertheless, these leaf-buds in their internal condition and endowments are totally different from the germs of the organs of fructification. All that the deciduous bud requires for its perfect development is, that new nutriment should be supplied to it from without, either by the soil or by another vegetating organism, on which it is engrafted. The semen of the male, on the contrary, far from merely yielding nutriment, however perfect, to the unimpregnated germ, really contains within itself, just as the germ of the female does, the power of determining the whole form of the species, whether plant or animal. This fact is evident in ordinary generation, as well as in the production of hybrids. The offspring in ordinary generation, possesses, not merely the properties of the mother, but those of the father also in an equally marked degree. This is matter of constant observation, in the generation both of man and of animals. The race, form of body, propensities, passions and talents of the father, as well as of the mother, are manifested in the progeny; and since these peculiarities are communicated to the germ by the semen, they must be contained in it, just as those of the female parent are contained in the germ. The same evidence is afforded by the intermediate forms resulting from the intermixture of different species. The mule partakes of the characters of both the horse and the ass; and the hybridising of plants as frequently gives rise to intermediate forms distinct from either parent plant, and not to be regarded as merely aborted individuals of either species. Hence, if the semen be denominated nutriment, it must be regarded as a kind of nutriment in which, no less than in the germ, are involved the specific form of the animal or vegetable, and all its individual peculiarities.

In the same way we may refute the theory of those physiologists, who regard the semen not as nutriment, but, on the contrary, as an agent which arrests the vegetation of the germ and the growth of the axis of the plant. For this arrest of vegetation occurs in plants where there are merely female flowers, and where no influence of the fecundating principle could be exerted. Moreover, since this fecundating principle has the power of determining the form of the male individual, it can be neither a mere stimulus nor an agent which simply arrests vegetation.

c. Of the nature of the ovum and semen, and of the process of conception.

The unimpregnated vegetable germ and the leaf-bud agree in both possessing "potentially" the specific form of the plant. They differ, however, from each other, in the flower-bud which contains the unimpregnated germ being unable, of itself, to put forth new buds; while the leaf-bud not only can develop itself to a new individual, but may become the stock from which an infinite number of new individuals are developed. The unimpregnated germ, therefore, though involving "in potentiâ" the form of the species, yet is, in consequence of a peculiar impediment to its organising action, unable to develop this form "in actu;" but the leaf-bud is free from such impediment. The organising action of a leaf-bud is certainly impeded when the nutriment necessary for vegetation is not supplied to it, as may happen to a deciduous leaf-bud. But the impediment to the organisation of the unimpregnated germ is much more intimately connected with its own constitution; for the germ does not undergo development even when it is supplied with the necessary nutriment. What, then, is the nature of this cause which prevents the organising action of the germ from being exerted? Since it is not merely want of nutriment, it most probably consists in the germ having defects in its constitution from which the leaf-bud is free, and which render the development of the germ in the pre-ordained form impossible. The semen or fecundating matter contains that which gives integrity to the germ. The semen, also, is capable of determining the specific and individual form of the new animal or plant, but it likewise is the subject of a defect which renders it incapable of actually developing that form, until it has united with the female germ. The defects, however, of the ovum, or germ, and of the semen, are not identical in nature, since each contains that in which the other is deficient. The ovum and semen are not similar halves of one whole. The ovum, at least that of animals, contains the part destined to germinate, and is, in fact, the primary cell, or contains the primary cells, which form the basis of the new organism, and maintain, unbroken, the chain of organisation. The semen, on the contrary, does not itself germinate, but is a fluid excitor of germination, endowed, at the same time, with the power of determining the form not only of the species but of the individual organism which produced it.

It may here be well to glance at the mode of vegetation of cells within developed organisms. The cells of vegetables have the power of transforming the nutriment brought into contact with them into a fluid productive matter, within which new cells are developed. The formation of the new cells in this plastic matter, the "cytoblastema" of Schleiden is determined by the influence of a pre-existing cell, and is effected by a definite process; nuclei being first formed, around which the young cells are developed. Schwann's researches have shown that the cells of the animal organism grow in the same way. The germ, therefore, which is really a cell, may be regarded as a primary cell endowed with the power of producing the specific form of the plant, but defective in the respect of being incapable of producing the "cytoblastema." The semen or fecundating matter, on the contrary, though capable of determining the power of the new organic being, contains no primary cells, but resembles, more nearly, a "cytoblastema," endowed with the property of producing a definite form, but incapable of vegetating except under the influence of a primary cell already formed. We may imagine, that when the primary cell of the germ, and the "cytoblastema" of the semen are brought together, the vegetation of the primary cell will commence; while, in consequence of both the primary cell of the germ and the plastic matter of the semen exerting an influence on the products of this vegetation, the new individual must present a mixture of the forms which the germ and semen had respectively a tendency to give, and will resemble both the male and the female parent.

BOOK IX.

OF DEVELOPMENT.

SECTION I.

OF THE DEVELOPMENT OF THE OVUM AND EMBRYO.

I. The development of the embryo of vertebrate animals is presented to us in its most simple form in fishes and the Amphibia.

In all animals some changes in the entire mass of the yolk seem to precede even the first modelling of the embryo. The extent of these changes, however, is very different in the different classes. They are least considerable in birds, and most so in Amphibia, fishes, and many invertebrate animals; in which they produce the phenomenon of the regular division and subdivision of the whole yolk.

The yolk has the most essential share in the development of the embryo. In some cases it is the portion of the yolk called the germinal membrane, which more especially contributes to the production of the new animal; in other cases, as in the frog, the entire mass of the yolk has this function. Rusconi was perfectly correct when he remarked that the embryo of the frog was formed from the whole yolk. The discoveries of Schleiden and Schwann respecting the growth of cells throw an unexpected light upon this subject.

Schwann has shown that the ovum of animals is a cell; that the membrane of the yolk sac represents the cell membrane, or wall of the cell; the germinal vesicle, the nucleus; and the yolk, the contents of the cell. He has further shown that the cells of the yolk are produced, in a manner conformable with the law regulating the development of all cells, within their parent cell, the ovum; and that the substance of the embryo itself is at first composed of cells. Schwann has likewise remarked that the yolk must be regarded not as mere nutritive matter, but in the light of a body having life; since the cells composing it take an essential part in the formation of the embryo. These cells effect a chemical change in their contents during the process of development, in consequence of which the yolk loses its coagulable property. Schwann, therefore, compares the yolk in respect of the share which it has in nutrition to the albumen of the embryo of plants. The proper albumen or white of the bird's egg entirely disappears during incubation, being absorbed as nutriment for the chick.

The further changes which the cells of the yolk undergo have been observed by Bischoff, Barry, and Reichert. Professor Bischoff and Dr. Barry recognised the development of cells within the yolk of the ovulum of Mammalia. Riechert has discovered that the formation of young cells within the previously existing cells composing the entire mass of the yolk is a process which continues during the whole period of development in frogs, where the entire yolk is employed in the building up of the embryo. In birds, according to the same observer, this process does not take place; the formation of young cells being there limited to that part of the yolk which more immediately contributes to the formation of the embryo.

CHAPTER I.

DEVELOPMENT OF MAMMIFEROUS ANIMALS AND MAN.

I. *Development of the ovum of Mammalia.*—The transit of the ovum from the ovary into the Fallopian tube sometimes takes place within a few hours after the act of sexual union: thus, Dr. Barry found that the ovulum of the rabbit left the ovary within nine or ten hours after the coitus. In other cases the process occupies twenty-four hours, or even several days.

De Graaf (*Opera Omnia*, p. 215,) observed, that the ovula of rabbits had been discharged from the ovary three days after the coitus. Cruikshank (*Phil. Transact.* 1797,) found them in the Fallopian tube on the third day, and on the fourth day in the uterus. Coste found ova of rabbits in the uterus twenty-four hours after sexual union. Wharton Jones detected the ova of a rabbit in the Fallopian tube, two days after impregnation; while in a rabbit which he examined forty-one hours after its connection with the male, no ova could yet be discovered either in the tubes or in the uterus. Prevost and Dumas, instituting an examination of two bitches eight days after impregnation, found ova in the uterus; and in one of the two a single ovum was also discovered in the Fallopian tube.

According to the researches of Bischoff, made on bitches, the period of the escape of the ova from the ovary is very different in different cases. The earliest time at which he detected ova external to the ovary was thirty-six hours. In one bitch, the ova had not left the Graafian vesicles nineteen hours after the act of sexual union. In another bitch, which fourteen days previously had ceased to have coitus with the dog, the ova had reached only the middle of the Fallopian tubes. A third bitch had refused the dog eleven days, and yet the ova had only just entered the uterus, and were very backward in their development. A remarkable fact, which seems quite unique, has been observed in the case of the ovum of the roe-deer. A very long period intervenes between the act of impregnation and the separation of the ovum from the ovary. The time of sexual union is August, while, according to the numerous observations of Pockels, (*Wiegmann's Archiv.* 1835, 195. *Müller's Archiv.* 1836, 183,) the ovum does not leave the Graafian vesicle and enter the Fallopian tube before December. The period of heat lasts from the end of July to the end of

August. The ovum therefore remains about four months after its impregnation before its development commences.

The primitive changes which the ovum undergoes in the Fallopian tubes, and in the uterus, have been described by Cruikshank, Prevost and Dumas, Von Baer, Coste, Wagner, Wharton, Jones, Bischoff, and Barry.

Dr. Barry* has made some remarkable observations relative to the changes which take place in the ovum immediately after impregnation,—observations which seem to bring us much nearer to a perfect acquaintance with that process. In immature ova, according to Dr. Barry, the germinal vesicle is situated at the centre of the yolk; but subsequently it passes to the surface. The ovum itself lies at first in the centre of the Graafian vesicle; but previously to impregnation is conveyed to that part of its surface which is nearest to the exterior of the ovary, and is held there by the "retinacula," described at page 1470. The germinal spot is at the same period placed at the surface of the germinal vesicle. Such is the condition of the mature ovum, *ante coitum;* that is to say, its essential parts lie as near as possible to the surface of the ovum and Graafian vesicle. *Post coitum*, but before the discharge of the ovum from the ovary, the germinal spot passes to the centre of the germinal vesicle, and the germinal vesicle to the centre of the yolk. The nature of these changes in the condition of the ovum, taking place after coitus, and the fact of spermatic animalcules having been traced to the ovary itself, render it exceedingly probable that these changes are produced by the contact of the seminal fluid. In further, and more minute researches,† directed to discover the state of the ovum at the moment of fecundation, as well as immediately before and after that event, Dr. Barry has made the following important observations:—He finds that the germinal vesicle is really the essential portion of the ovum, and that it is the seat of the most important changes which immediately follow impregnation. "It is known that the germinal spot presents, in some instances, a dark point in its centre. The author finds that such a point is invariably present at a certain period; that it enlarges, and is then found to contain a cavity filled with fluid, which is exceedingly pellucid. The outer portion of the spot resolves itself into cells; and the foundations of other cells come into view in its interior, arranged in layers around the central cavity; the outer layers being pushed forth by the continual origin of new cells in the interior. The latter commence as dark globules in the pellucid fluid of the central cavity." "The germinal vesicle, enlarged and flattened, becomes filled with the objects arising from the changes in its spot, and the interior of each of the objects filling it, into which the eye can penetrate, presents a repetition of the process above described. The central portion of the altered spot, with its pellucid cavity, remains at that part of the germinal vesicle which is directed towards the surface of the ovum, and towards the surface of the ovary. *At the corresponding part, the thick transparent membrane of the ovum, in some instances, appears to have become attenuated, in others also cleft.* Subsequently the central portion of the altered spot passes to the centre of the germinal vesicle; the germinal vesicle, regaining its spherical form, returns to the centre of the ovum, and a fissure in the thick transparent membrane is no longer seen. From these successive changes it may be inferred that fecundation has taken place; and this by the introduction of some substance into the germinal vesicle from the exterior of the ovary. It may also be inferred, that the central portion of the altered germinal spot is the point of fecundation. In further proof that such really is the case, there arise at this point two cells, which constitute the foundation of the new being. These two cells enlarge, and imbibe the fluid of those around them, which are, at first, pushed further out by the two central cells, and subsequently disappear by liquefaction. The contents of the germinal vesicle thus enter into the formation of the two cells. The membrane of the germinal vesicle then disappears by liquefaction."

The further changes which Dr. Barry has found the essential parts of the ovum to undergo, up to the formation of the embryo, are as follows:—Each of the twin cells gives origin to two others, making four: each of these four in turn gives origin to two, by which the number is increased to eight; and this mode of augmentation continues until the germ consists of a mulberry-like object, the cells of which are so numerous as not to admit of being counted. Together with a doubling of the number of the cells, there occurs a diminution of their size. Every cell, whatever its minuteness, is found filled with the foundations of new cells into which its nucleus has been resolved. These foundations of new cells are arranged in concentric layers around a pellucid point. Each cell in fact exhibits the same process of cellular development as the original parent cell—the germinal vesicle. The foregoing changes usually take place in the ovum during its passage through the Fallopian tube. When it has entered the uterus, a layer of cells of the same kind as those forming the mulberry-like body makes its appearance on the whole of the inner surface of the membrane which invests the yolk. The mulberry-like structure then passes from the centre of the yolk to a certain part of that layer; the vesicles of the latter coalesce with those of the former, where the two sets are in contact, to form a membrane—the future amnion; and the interior of the mulberry-like structure is now seen to be occupied by a large vesicle containing a fluid and dark granules. In the centre of the fluid of this vesicle is a spherical body, composed of a substance having a finely granular appearance, and containing a cavity filled with a colourless and pellucid fluid. This hollow spherical body seems to be the true germ. The vesicle containing it disappears, and in its place is seen an elliptical depression filled with a pellucid fluid. In the centre of this depression (which appears to correspond to the area pellucida of the bird's egg) is the germ still presenting the appearance of a hollow sphere.

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* Researches in Embryology, second series, Philos. Transact. 1839, pt. ii. pp. 312 to 316.

† Researches in Embryology, third series, read at the Royal Society, May 7, 1840; see London and Edinb. Phil. Mag. June, 1840, and Phil. Transact. 1840, pt. ii. p. 529.

From the germ the embryo now begins to be formed. The germ separates into a central and a peripheral portion, both of which, at first appearing granular, are subsequently found to consist of vesicles. The central portion occupies the situation of the future brain, and soon presents a pointed process. This process becomes a hollow tube, exhibiting an enlargement at its caudal extremity, which indicates the situation of the future sinus rhomboidalis. Up to a certain period new layers of vesicles or cells come into view in the interior of the central portion of the germ, parts previously seen being pushed further out.

According to Dr. Barry, there is no structure in the mammiferous ovum entitled to be denominated the "germinal membrane." The "amnion" is formed, as has already been mentioned, from an epithelium-like layer of cells which lines the investing membrane of the ovum, and from the outer cells of the mulberry-like body, which together constitute a layer corresponding to the "lamina serosa" of authors. The "vascular lamina" of the umbilical vesicle arises as a hollow process originating from the germ and extending beneath the amnion so as to include the yolk.*

The "yolk-sac" of the mammiferous ovum communicates with the intestine of the embryo, at first by a wide opening, and afterwards by a duct or hollow pedicle, the "ductus omphalo-mesentericus," which is accompanied by the same vessels as in the bird, the "vasa omphalo-mesenterica." This yolk-sac of Mammalia is commonly called the "umbilical vesicle, or vesicula umbilicalis." According to Von Baer's researches, it has an external vascular layer, and an internal mucous layer, from which villous prolongations project into the yolk. These villi or folds, which are similar to those found in the yolk-sacs of birds, exist likewise in the umbilical vesicle of the human ovum. The "amnion" was observed by Von Baer to hold the same relation to the abdominal plates of the embryo, as in the bird [illegible] developed in the same manner. The "allan [illegible] the same process as in birds; its formation has been elucidated, more especially by the researches of Von Baer and Coste. Its blood-vessels are the "vasa umbilicalia."

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* This notice of Dr. Barry's observ

Before the formation of the urinary bladder, the allantois communicates with the common reservoir, into which the excretory ducts of the Wolffian bodies, the ureters, and the organs of generation open, which is called the "sinus urogenitalis." The urinary bladder is developed from the apex of this cavity; and for a certain period it is continued into the pedicle of the allantois or the urachus. The amnion passing off from the margin of the umbilicus, and forming a bladder-like investment for the fœtus, encloses, as a sheath, all the parts which issue from the umbilicus; namely, the pedicle of the umbilical vesicle or yolk-sac, the vasa omphalo-meseraica, the pedicle of the allantois, and its blood-vessels, the vasa umbilicalia. These parts are thus united into a common cord, the "funiculus umbilicalis;" and the sheath of this cord the "vagina funiculi umbilicalis," is consequently formed by the amnion. Through the medium of the vessels of the allantois, the vascular system of the fœtus reaches the "chorion," in the substance of which, and in its villi, the allantoid or umbilical vessels ramify.

While the ovum is undergoing the first changes of development in the uterus, it lies quite free in the cavity of that organ. But subsequently an exudation is poured out upon the inner surface of the uterus which is composed of cells, and constitutes the thin "membrana decidua" of the mammiferous ovum. Into this membranous uterine production, which is especially distinct in carnivorous animals, (*Bojanus*, loc. cit.) the villi, growing from the chorion of the ovum, become inserted. At a still later period, the ovum enters into another kind of union with the uterus, by means of the placenta, the structure of which will be described hereafter.

2. *Development of the human ovum.*—The human ovum, in all probability, does not reach the uterus before the lapse of a week after impregnation. On the eighth day, Von Baer could detect no ovum either in the uterus or in the Fallopian tube. Home and Bauer state, that they found an ovum on the seventh day; but some doubt attaches to their observation. The ovum observed by E. H. and E. Weber was of the date of a week after impregnation. The earliest ova examined by Velpeau, belonged to a period between the tenth and twelfth days; they were already beset with villi, but presented no embryo. In an ovum of fourteen days Von Baer saw the embryo.

Before the ovum reaches the uterus, the formation of a new structure, the "membrana decidua," upon the inner surface of that organ, and corresponding, therefore, to its inner surface in form, has commenced. Ed. Weber observed it on the seventh day after coitus had taken place. It then resembled a layer of lymph, effused from the inner surface of the uterus, upon and between the enlarged vascular villi of that surface.* This membrane exists in animals also; but in a less highly developed form. It is sometimes formed in the uterus of the human female, in cases of extra-uterine fœtation, though not always; and in a case of development of the ovum in the Fallopian tube, the membrana decidua has been observed both in the uterus and in the tube. The membrana [illegible] composed of a whitish grey, moist, and soft mass, similar to [illegible] and entirely formed of nucleated cells.† The vessels

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riorum puellæ, vii. a conceptione die defunctæ.

hor, on the cellular structure of the decidua in Schwann's of the uterus are prolonged into this product. The thickness of the membrane sometimes equals from one to three lines. Its outer surface is intimately connected with the uterus, and when artificially detached, or separated spontaneously, is rough, while its inner surface is smooth. The relation which the decidua bears to the openings of the uterus is not always the same; it is sometimes closed at the lower orifices of the Fallopian tubes, and at the upper entrance of the cervix uteri; sometimes it is open at all these points or at one or other of them. R. Wagner (*Meckel's Archiv.* 1830, *and Physiologie,* p. 114–117,) is quite correct in stating that all these varieties may occur. The cervix uteri is occupied by a mere gelatinous mucus.

When the ovum enters the uterus, it becomes imbedded in the structure of the decidua which is yet quite soft. The earliest ova which have been observed in connection with the decidua, were not contained free in its cavity, but appeared to be implanted in it or pressed into it from without; the decidua, at the point of entrance of the ovum, being protruded inwards, and the ovum contained in a hollow of its external surface. (See *Bock, de Membraná deciduá.* Bonnæ, 1831.) During the further growth of the ovum, the decidua becomes more and more inverted at this point, the inverted part being received into the cavity of the rest of the membrane. This inverted portion is called the decidua reflexa, while the other part of the membrane is called the decidua vera. The decidua vera and the decidua reflexa have the same structure, which differs totally from that of the mucous membrane of the uterus. They are, in fact, new products. It must not be imagined that the process by which the decidua reflexa is formed, is a mechanical one, that the ovum, as it enters the uterus, pushes the membrane before it; for, like all processes of the same kind, which occur in the animal organism, this one is effected by the vital vegetative action exerted in a determinate direction. The cavity of the decidua between the decidua vera and the decidua reflexa, contains an albuminous fluid, the "hydroperione" of Breschet. At the part where the uterine expansion of the decidua is interrupted by the reflexion inwards of the decidua reflexa, and where the ovum entered, the place of the former membrane is supplied by another mass similar to it, and connected at its margins with it, the "decidua serotina." When young ova are examined in the uterus both the decidua vera and the decidua reflexa are generally found; but in aborted ova this is seldom the case, a part of the decidua being most frequently retained in the uterus. As the ovum increases in size, the decidua vera and the decidua reflexa gradually come into contact, and in the third month of pregnancy the cavity between them has quite disappeared. Henceforth it is very difficult, or even quite impossible to distinguish the two layers. During the further growth of the ovum the decidua becomes still thinner, but is not entirely lost. At birth a part of it remains behind in the uterus, while a part comes away, forming a thin membranous covering of the ovum.*

The first connection which subsists between the ovum and the decidua, consists in the ramified villi of the chorion becoming imbedded in the hollow canals which traverse the decidua. The villi extend through these canals in the manner of roots, and thus draw nourishment from a maternal structure without having any organic connection therewith.

According to the recent researches of E. H. Weber communicated to me in manuscript, the decidua is composed in greater part of the tubular follicles, which lie very closely arranged at the inner surface of the uterus, and of numerous blood-vessels ramifying upon, and between them. In animals, the long tubular follicles, here and there bifurcated, lie in the substance of the uterus itself, and open upon its inner surface

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paper, in Froriep's Notiz. 1838. No. 112, p. 22. See also R. Wagner, Physiologie, p. 114, and Icon Physiol. Tab. xi. fig. 5 [illegible]

* Respecting the decidua of the mature [illegible] Bischoff, Beiträge zur Lehre von den Eihüllen des menschlichen Fotus. Bo [illegible]

by numerous orifices.* In the human subject they form the decidua.† When the inner surface of the decidua is examined, numerous filaments can be seen in its substance; tolerably regularly disposed, and directed towards the surface. These filaments resemble closely set villi, except that they do not lie free; the interspaces between them being filled with the substance of the decidua. If the cut surface of a divided uterus is examined in the bright sunlight, with a lens, these supposed villi are seen to be long and thin cylindrical tubuli, which become somewhat narrowed where they reach the free surface of the decidua, while at the attached or uterine surface of that membrane they become wider, are much convoluted, and appear to commence by closed extremities. If the substance of a pregnant uterus is compressed, a thick whitish fluid exudes upon the surface of the decidua, similar to the secretion which may be expressed from the uterine glands of animals. The decidua presents at its inner surfaces numerous orifices, which have been long known, and which appear to be the mouths by which two or more of the tubuli open. Besides these, however, there must be many orifices of single tubuli which are not visible. The tubuli are almost a quarter of an inch in length, and here and there bifurcate; the branches being as wide as the trunk of the follicle. This character completely distinguishes them from the blood-vessels which run in contact with them; for the blood-vessels form a net-work or loops, or at all events ramify, diminishing in diameter at each division. The diameter of the follicles is about $\frac{1}{17}$ of a Paris line; that of the capillaries $\frac{1}{164}$ of a Paris line.‡

Connection of the fœtus with the uterus in Mammalia and Man.§

The ovum appears to have a firm connection with the uterus in all Mammalia, with the exception of the Marsupialia and Monotremata. The means of attachment are always either vascular villi or folds of the chorion, and the chorion receives its blood-vessels from the vasa umbilicalia of the fœtus, which are distributed upon the allantois, and by it are conducted to the chorion. The villi are sometimes distributed over the whole surface of the chorion, as in the Hog family, the Solidungula, the Camel family, and the Cetacea; sometimes they form a zone around the ovum, as in Carnivora; at other times they are collected into several masses scattered over the chorion, the cotyledons, as in most Ruminantia; and lastly, in man and some other animals they form a single placenta upon one side of the chorion. The double placenta sometimes observed in the Rodentia approaches closely to the last form. Corresponding to the vascular villi of the fœtal chorion and placenta there are depressions upon the inner surface of the uterus in which the villi are imbedded like roots in the soil. When the villi are aggregated together at particular points of the chorion so as to form cotyledons, the uterus has at corresponding points maternal cotyledons,—projecting cup-like bodies, pierced by innumerable tubular cavities, which receive the villi of the fœtal cotyledons. In the human subject the placenta uterina is a growth of the decidua uterina, which at the part corresponding to the fœtal placenta undergoes an excessive development, and penetrates the substance of the fœtal placenta, passing between the tufts of villi even as far as the chorion. In all cases, whether the villi are scattered over a wide surface, or aggregated into masses, the object attained is a great increase of the surface of contact between the chorion and the uterus. Two principal modifications of the form in which this increase of surface is given are to be observed, namely, the development of ramified villi imbedded in the uterus, and the formation of folds on both chorion and uterus, which are interposed between each other.

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* See E. H. Weber, in his Edition of Hildebrandt's Anatom. Bd. iv. p. 505. Burckhardt, Obs. Anat. de uteri vaccini fabricâ. Basil. 1834. E. H. Weber, Annot. Anat. 186.

† Engraved representations of the Decidua will be fonnd in Dr. Hunter's Gravid Uterus, Plates 33 and 34; in Velpeau's Embryologie, Paris, 1833; in Seiller's Gebärmutter und das Ei des Menschen in den ersten Schwangerschaftsmonaten. Dresden, 1832; in Kilian's Gehurtshülfl. Atlas. Tab. xxiv.; and in C. Mayer's Icones Selectæ. Bonn, 1831, Tab. v. Figs. 6, 7, and 8.

‡ Dr. Sharpey has been for some time engaged in investigating the structure and functions of the membrana decidua and the uterine glands.

§ Writings on the subject. Von Baer, Untersuchungen über die Gefässverbindung zwischen Mutter and Frucht in den Säugethieren. Leipz. 1828. E. H. Weber in Hildebrandt's Anatomie, Bd. iv. p. 496, in Froriep's Notiz. 1835, Bd. 46, p. 90. and in Wagner's Physiologie, p. 124. Eschricht, de organis, quæ respirationi et nutritioni [illegible] animalium inserviunt. Hafniæ. 1837.

The Placenta.—The human placenta is throughout composed of two elements, the parts of the placenta fœtalis and those of the placenta uterina intermingled. The fœtal placenta consists entirely of dense tufts of branched vascular villi, whilst the uterine placenta is formed of the substance of the decidua, which penetrates between the villi of the fœtal placenta even to the surface of the chorion, and completely encloses them. The exact relation which the two parts bear to each other is, however, according to Professor E. H. Weber, very different in man and in Mammalia. In Mammalia the vascular villi of the fœtus are received into the vascular sheaths of the uterine placenta, so that the capillaries of the fœtal and those of the maternal system come into contact with each other, and suffer an interchange of the matters which they contain. In the human subject, on the contrary, the vascular villi of the fœtus dip into wide blood-vessels, which arise from the uterine system, and which permeate the whole uterine portion of the placenta; the looped capillaries of the fœtus being thus surrounded and bathed, as it were, in the maternal blood. The ends of the villi are formed by the inosculating loops of the minute arteries and veins of the fœtus; which, however, have the distinguishing character that the same vessel makes several turns from one loop into another before it enters the nearest venous trunk. The vessels belonging to the maternal system, which penetrate the uterine portion of the decidua and in all parts contain villi of the fœtal portion, may be readily filled with injection from the arteries of the uterus. Eschricht inclines to the opinion, that in man as in Mammalia, only the capillaries of the decidua come into contact with the looped vessels of the villi. Weber, on the contrary, maintains that the uterine arteries and veins on entering the spongy substance of the placenta, no longer ramify and give off branches and twigs, but take the form of a net-work, the canals of which are much larger than the ordinary capillaries. The extremely thin parietes of these canals, according to Weber, apply themselves to all the branches and capillary loops of the vessels which form the fœtal villi, so that even here the structure consists essentially in two sets of vessels being brought into the closest possible contact.* The recent observations of Dr. J. Reid (Edinb. Med. and Surg. Journ. No. 146,) agree in the most important points with those of Weber, but yet differ from them in some particulars. According to Dr. Reid, the blood sent from the mother to the placenta is poured by the curling arteries of the uterus "into a large sac formed by the inner coat of the vascular system of the mother; which is intersected in many thousand different directions by the placental tufts projecting into it like fringes, and pushing its thin wall before them in the form of sheaths, which closely envelope both the trunk and each individual branch composing these trunks. From this sac the maternal blood is returned by the utero-placental veins without having been extravasated, or without having left her own system of vessels." The uterine vessels, according to Dr. Reid, do not form a network in the substance of the placenta as described by Weber. Further, Dr. Reid has observed, that the tufts of the placental vessels are prolonged into some of the uterine sinuses, a fact not noticed by Weber. Dr. Reid states also, that in the placental tufts each branch of the umbilical artery is bound up with a branch of one of the umbilical veins, and that both of them divide and subdivide exactly in the same manner, and terminate by inosculation with each other at the blunt extremities of the branched tufts. It appears, however, that this description of the structure of the placental tufts is erroneous. In a paper on the structure of the placenta, recently sent in to the Royal Medico-chirurgical Society by Mr. Dalrymple, most satisfactory confirmation is given to Weber's account of the mode of termination of the fœtal vessels in the placental tufts. Several drawings, made by Mr. Dalrymple before he had seen the figures given by Weber in Wagner's Icones, bear the most remarkable resemblance to those figures. The minute arteries and veins are not bound up together, two and two; but the same capillary tube, arising from an arterial trunk, makes several convolutions and forms several loops before it terminates in a vein.

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* See the account of Weber's more recent researches in connection with this subject in Wagner's Physiologie, p. 124.

In the human subject, as in Mammalia, there is no passage of blood from the vessels of the mother into those of the fœtus, and *vice versâ*. When the placenta is injected from the vessels of the mother, as can be readily done, only the vessels of the maternal portion of the placenta are filled. And, on the other hand, the passage of injected matters from the umbilical arteries, or vein, of the fœtus into the vessels of the uterus, by no means proves the existence of a communication between the two sets of vessels; for the injected mass becoming extravasated from the vascular loops of the fœtal placenta, must pass directly into maternal vessels, and if forced onwards necessarily fills the veins of the uterus.

The placenta fœtalis and the placenta uterina can be separated in some animals with great ease, and without injury to either; but in other animals and man they cannot be detached from each other without laceration. Von Baer remarks that the fœtal cotyledons of the Ruminantia, when they are only slightly developed, adhere so firmly to the maternal cotyledons which form sheaths for the villi, that it is impossible in their fresh state to withdraw them uninjured. But after a short period has elapsed they are easily separable, and then, according to Von Baer, there is always found between the embryonic and the maternal part of the cotyledon a mass of thickish consistence, the origin of which is a matter of doubt. It may be derived either from the sheaths of the maternal cotyledon, or from the villi of the fœtal cotyledon, or from both. It has probably formed a layer of active organic cells, which played an important part between the two systems of vessels. When the cotyledons of the ruminants separate at the time of birth, the vascular tufts of the villi remain uninjured. The Mammalia present great varieties in the process of the separation of the placenta. E. H. Weber divides these varieties into two classes. To the first class belong those cases in which the two placentæ (the fœtal and the uterine) are so loosely connected that they separate without either receiving any injury. The uterus here suffers no lesion, and the uterine placentæ remain after birth, and merely diminish in size: this is the process in the ruminants, horses, and hogs. The second class includes those instances where the two portions of the placentæ are so intimately united that the uterine portion is torn away, together with the fœtal portion, at the time of birth. Here the uterus receives a wound, and the placentæ are deciduous organs, which must be renewed at each gestation. This class is exemplified in man, the Carnivora and the Rodentia. (*See Froriep's Notiz.* 46 Bd. p. 90. *Compare Eschricht, loc. cit.*)

Nutrition of the Fœtus.—There is a period in the growth of the ovum which precedes the development of blood-vessels. Since the chorion and its villi are composed of nucleated cells, similar to those which are the active agents in the growth and vegetative changes of the primitive structures of the embryo, previous to the formation of vessels and the circulation of blood, the growth of the villi of the chorion long before the development of the blood-vessels is an intelligible phenomenon. These villi then attract matters from the surrounding fluids, and, like the cellular structures of plants, convey them onwards, transmitting them from one cell to another, until they accumulate in the interior of the ovum. This is the essential process in all organic absorption, even when blood-vessels and lymphatics exist; for even in the intestines the vascular villi are invested by a sheath formed of nucleated cells, which exert the same action as the cortical cells of the spongiola of the roots in plants. When the blood-vessels of the embryo have reached the chorion and its villi, these blood-vessels which have been developed from cells, and participate in the active properties of cells, absorb the nutriment. The nutritive matters thus absorbed are supplied either by the blood of the mother in which the villi float, as in the human placenta, or as in Mammalia by the white secretion of the uterine glands. The absorbed nutriment enters directly into the blood of the fœtus. The process thus maintained between the fœtal and the maternal blood supplies the process of respiration to the fœtus, or an equivalent for that process.

There is no other mode of nutrition to which great importance can be ascribed. It is true, the amnion may, by the organic action of its cells, absorb fluids from the chorion, and deposit nutriment in the form of a small quantity of albumen in the liquor amnii. The liquor amnii enters the mouth of the fœtus, and certainly reaches the intestinal canal as well as the trachea. For in the stomach of the fœtus of the human subject, as well as of mammiferous animals, there have been found hairs derived from the lanugo or first hair of the fœtus, which falls out and becomes mixed with the liquor amnii. But this mode of nutrition by means of the liquor amnii can at most be of very trifling and very inadequate amount.

SECTION II.

OF BIRTH AND THE CHANGES OF DEVELOPMENT WHICH TAKE PLACE AFTER BIRTH.

CHAPTER I.

Of Birth.

a. The process of birth.—In nine solar or ten lunar months the development of the human embryo is completed. During this period the uterus serves as the medium of communication between the maternal system and the fœtus, and itself undergoes an increase of substance, by the constant development of new muscular fibres of organic life. These muscular fibres are developed by the same process as that by which muscles are originally formed in the embryo; hence at this period all the stages in the development of this tissue may be observed simultaneously in the uterus.* The muscular power of the uterus, however, remains in a latent state. When the process of development is complete, the child becomes independent of the maternal system, and is as it were a foreign body in the uterus, which reacts against it by muscular contractions. These contractions of the uterus are the cause of birth. Similar contractions of the uterus, however, occur even when the fœtus is not contained in its cavity, (in graviditas extra-uterina,) at the time of the interruption of the physiological connection between the mother and the child. The contractions of the uterus being attended with the violent compression of living structures, are generally productive of pain, and hence are called "pains." They recur at regular periods, but even in the intervals of the "pains" the uterus is not relaxed but continues to embrace its contents. After birth the contractions of the uterus are still repeated for a certain length of time, and are then called "after-pains." In women who have died before giving birth to their child, contractions of the uterus have frequently taken place after death, and have caused the expulsion of the fœtus when the mother has been no longer living. The uterine contractions appear to commence at the os uteri, to be propagated towards the fundus, and again to return thence towards the mouth of the uterus. By this succession of muscular contractions the fœtus is first raised and then propelled downwards towards the os uteri, when the lips or sphincter of the latter part become thinned and dilated. These movements, like those for the expulsion of the urine or fæces, when energetic, are aided by the muscles of the abdominal parietes and the diaphragm, which diminish the cavity of the abdominal capacity from above, from the front, and from the sides. The action of these voluntary muscles under these circumstances is involuntary and regulated by the law of the consentaneous movements as well as by that of the reflected movements; for the uterus is the seat both of violent movements and of intense impressions on sensitive, or centripetal nerves. At the same time many of the muscles of the trunk exhibit a tendency to consentaneous effort; the extremities seek points of resistance; the breath is held; and the arms seize anything which is capable of giving support during the contraction of the abdominal cavity. In the last month of pregnancy the uterus sinks lower in the pelvis. Towards the termination of the period of utero-gestation, also, the position of the fœtus is such that its long axis corresponds to the long axis of the uterus, and that some part, generally the head, applies itself to the os uteri or "presents" itself. The knees of the child are drawn up, the arms folded across the breast, and the head pressed down towards the sternum. In the process of birth the part of the child, passing through the pelvis, adapt their longest diameter to the longest diameter of each region of that cavity, and hence they make a spiral turn. In the most frequent cases, those in which the head presents, the process is generally as follows. The antero-posterior diameter of the inlet of the pelvis will not allow the passage either of the greatest (antero-posterior) diameter of the head or of the breadth of the hips of the child, but the head of the child can pass with its long diameter either in the transverse or in the diagonal or oblique diameter of the pelvis. Birth begins by the long diameter of the head of the child being placed in the oblique diameter of the inlet of the pelvis. As the successive pains cause the head to descend lower, its long diameter comes to correspond with the antero-posterior diameter of the cavity of the pelvis, so that in the most common variety of head presentations the vertex and occiput are now placed under the pubes, while the face looks towards the hollow of the sacrum. In consequence of the curvature of the canal of the pelvis, the part of the child which descends along the anterior wall of the cavity travels through a very small space, while the part descending along the posterior wall describes a large arc of a circle.

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* Not less remarkable is the development which the nerves of the uterus undergo during pregnancy. These nerves have been dissected with great labour both in the impregnated and in the unimpregnated uterus by Dr. R. Lee, and will be described by him in the forthcoming volume of the Philosophical Transactions.—*Translator.*

The process of birth is usually divided into several stages. The first comprehends the period extending from the commencement of the "pains" to the opening of the os uteri; the second reaches to the rupture of the membranes of the ovum. This takes place when, the os uteri having opened, a part of the membranes containing the liquor amnii are protruded through it in the form of a pouch; this pouch bursts and the "waters" escape. The third stage extends from the rupture of the membranes to the presentation of the head at the outlet of the pelvis. During this stage the head descends through the dilated os uteri into the vagina. In the fourth stage the occiput escapes from the external parts of generation, whereupon the other parts of the child follow, the shoulders entering the pelvis in the oblique diameter of its inlet, and leaving it in the antero-posterior diameter of its cavity. During the last stage of birth, the "after-birth," consisting of the placenta and the membranes of the ovum, is expelled. For after the birth of the child the contractions of the uterus continue; and in consequence of the part to which the placenta was attached becoming very much contracted, that organ is separated, an effusion of blood taking place from the torn vessels. The separation and expulsion of the placenta occur in from half an hour to an hour after the birth of the child; so that all the stages of delivery are completed in the space of six or twelve hours. When the after-birth is expelled, the uterus contracts still more closely.*

In animals the process of birth is in general attended with less difficulty than in the human species, both on account of the wedge-like form of the head of the fœtus, which is preceded in its passage through the pelvis by the fore-feet, and on account of the greater mobility of the os coccygis.† In the vampires the birth of the young is facilitated by the pubic bones not being united in the middle line in these animals, and in Cavia aperea and other animals by the symphysis pubis being capable of dilatation.

b. The mother and child after birth.—The child breathes immediately, and cries as soon as its respiratory organs are relieved from the pressure to which they were subjected during birth. The umbilical cord is tied and divided by the persons assisting at the labour. In brutes the umbilical cord generally becomes ruptured spontaneously during birth at a soft spot not far distant from the navel; in some cases it is bitten asunder by the mother. The umbilical vessels soon contract, so that their cavity is quite obliterated. During the first two or three weeks after birth, also, the foramen ovale in the septum auriculorum, and the ductus arteriosus Botalli become closed; and hence from this period all the blood sent to the body must pass through the lungs, and *vice versâ;* the pulmonary circulation now becoming a part of the general circuit which the whole mass of blood performs, whilst before merely a fraction of the blood in the general circulation traversed the lungs.

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* See F. C. Naegele, Ueber den Mechanismus der Geburt, in Meckel's Archiv. t. v. 1819, p. 483. Hueter, im Encyclopæd. Wörterb. d. Med. Wiss. xiv. p. 44. Those readers who desire more full information respecting the process of birth and its variations, should consult the above treatises and special works on midwifery,—such as those of Carus, Stein, Busch, Kilian, Ritgen, and H. F. Naegele.

† See Stein, Unterschied zwischen Mensch und Thier im Gebären. Bonn, 1820.

The newborn mammiferous animals instinctively seek the teats of the mother, and the newborn child also exhibits a constant impulse to suck every object which is offered to it.

In the maternal organism, during the first days of the puerperal state, the secretion of milk, which had shown itself in a slight degree during pregnancy, becomes suddenly increased, and the organic activity which was previously expended in the uterus is now transferred to the breasts; while all the maternal feelings at first expressed in the mother's joy at the birth of her living but helpless offspring, are concentrated in the fond office of nourishing and protecting the child. A bloody discharge in moderate quantity, the "lochia," flows from the female organs during some days after birth, and then is succeeded by a serous discharge which gradually, as the inner surface of the uterus regains its state of integrity, becomes a mere mucous secretion. The secretion of milk is excited in increased quantity by the mechanical irritation of the nipples during the act of sucking, and by all ideas of the mother relating to the nourishing and presence of the child. When once in existence, this secretion may often be maintained for a very long and indefinite period, as is observed in brutes, and sometimes also in the human female. Usually, however, it diminishes in quantity when the menstrual flux reappears about the ninth month. In women who do not suckle their children, the menstrual flux is generally restored at an earlier period, about the sixth week after birth.

The milk of pregnant women, and of puerperal women, immediately after birth, is called the "colostrum." According to the observations of M. Donné, it contains, besides the ordinary milk or fat globules, peculiar granulated corpuscules which may be detected in it until about the twentieth day after birth. The proper milk globules which give the milk its white colour consist principally of fatty matter; but they seem to be invested by a layer of some other substance, since they are not very readily dissolved by alcohol and ether. When milk is left at rest, the fat globules collect, for the most part, at the surface of the fluid and form the cream, which consists of the fat of milk or butter. When milk is subjected to continued agitation, the fat globules coalesce and form butter; and when this is removed, merely the fluid part of the milk remains. This fluid holds in solution the other components of milk,—namely the casein, the sugar of milk, and the salts. The fatty matter of milk is one of those fats which are destitute of nitrogen, and convertible into soap.

The casein is soluble both in warm and in cold water, and is not coagulated by boiling. It is precipitated by alcohol, corrosive sublimate, alum, and acetate of lead; the precipitate in every case being redissolved by water after the reagent has been removed by washing. Acids in small quantities precipitate the casein; but when added in excess, they redissolve the precipitate. Pepsin and the rennet containing it exert a peculiar action on casein; they precipitate it and at the same time render it insoluble in water. The ferro-cyanuret of potassium renders the solution of casein in acids turbid, or precipitates the casein. In respect of its elementary composition, casein, and consequently milk, are to be ranked amongst the nutritive substances which abound in nitrogen. According to Mulder's analysis, it contains, in addition to a small proportion of sulphur (namely 0.41)—

Carbon	55.10
Hydrogen	6.97
Nitrogen	15.95
Oxygen	21.62

Both the other principal ingredients of milk, the fatty matter, and the sugar of milk, are destitute of nitrogen. After the separation of the butter and the casein from milk, the sugar remains in solution. The sugar of milk crystallizes readily: when pure it is not susceptible of fermentation: but, under the influence of the azotised casein, it appears to become changed into sugar of mucus. The composition of the sugar of milk, according to the analyses of Gay-Lussac, Thenard, Prout, and Berzelius, is as follows:—

Carbon	40.46
Hydrogen	6.60
Oxygen	52.93

Fresh milk of the human female is slightly alkaline; cow's milk, even when fresh, is sometimes feebly acid; but, when allowed to stand for some time, and especially when the atmosphere is in a state of electric tension, all milk becomes acid owing to the transformation of some of its components, probably of the sugar. The acid of sour milk is lactic acid.

The milk of different animals is not identical in all respects. Simon found that the casein of the milk of the human female was not precipitated by acids. This was probably owing to the small quantity of the casein contained in the milk, and the large quantity of acid added. For a diluted solution of casein is not precipitated except by the smallest quantity of acid. A slight excess of acid redissolves the casein.

The milk of the human female is, according to Payen, of the following composition:—

Butter	5.18	5.16	or 5.90
Casein	0.24	0.18	or 0.25
Solid residue of the evaporated fluid of the milk	7.86	7.62	or 7.93
Water	85.80	86.00	or 85.50

Cow's milk, from which the cream had been removed, was found by Berzelius to contain:—

Of casein, with a portion of the fatty matter	2.600
Sugar of milk	3.500
Alcoholic extract, lactic acid and its salts	0.600
Chloride of potassium	0.170
Alkaline phosphate	0.025
Phosphate of lime, free lime combined with caseine, magnesia, and traces of oxyde of iron	0.230
Water	92.875

The specific weight of human milk, is from 1.020 to 1.025; that of cow's milk, 1.03.*

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* See Donné, Du lait et en particulier de celui des Nourrices. Paris, 1837. Müller's Archiv. 1839, p. 182. Henle, Froriep's Notiz. 1839, p. 223. Simon, die Frauenmilch. Berl. 1838. Marchand in Encyclop. Wörterb. d. Med. Wissensch. 23 Bd. p. 309.

CHAPTER II.

OF THE DIFFERENT AGES OR PERIODS OF LIFE.

Processes of development continue to be in operation after birth through a great part of life, although they are of a less important nature than those perfected in the fœtal state. It is only in a few classes and orders of animals which undergo metamorphoses, (as the Insecta, some Crustacea, the Cirrhopoda, the Hydrachinda amongst spiders, and the Amphibia amongst Vertebrate classes), that fundamental changes of form, and the new development of organs and groups of organs, are observed after the termination of embryonic life. The changes of development which occur in the higher animals and man after birth are limited to certain modifications of form, &c., which mark the different ages or period of life. Adopting that division of the life of a human being which is defined by the most remarkable processes of development or by their completion, we may distinguish the following ages or periods of life.

1. *The period of embryonic life.*—During this period the processes of formation and growth are in their greatest activity. The organs which are being formed present none of their functional phenomena, or only the gradual commencement of them. In the Amphibia there is no distinction of sex during embryonic life; in fact, the organs of generation are not formed. These organs are developed in the larva a considerable time after its escape from the ovum. In the rest of the Vertebrata, however, the distinguishing marks of the sexes become manifest during embryonic life. The causes which determine the sex of the embryo are unknown, although it appears that the relative age of the parents has some influence over the sex of the offspring.[*] In animals which bring forth many young at a birth, one act of coitus produces both males and females, and in those animals in which the impregnation of the ova is effected out of the body, the same seminal fluid fecundates ova which yield young of both sexes. But how different soever the proportion of the sexes in different families, in larger numbers they always bear an equal proportion. The law which effects this equalisation of the numbers of the sexes is in operation in each individual of the species. The equalisation of particular deviations from the general proportion is the result of an original provision, just as is the balance of the gain and loss, or of the "even" and "odd" in lotteries or any game of chance which is governed by a general law.

2. *The period of immaturity.*—This period extends from birth to puberty. It is marked by growth, by the development of the forms of the different parts of the body, and by the gradual perception and analysis, by the mind, of the different phenomena of the senses. Several

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[*] See Girou de Bouzareingues, Ann. d. Sc. Nat. t. xi. pp. 115, 314; t. xiii. p. 134. Hofacker, De qualitat. parent. in sobol. transeunt. Diss. præs. Tubing. 1827; and Heusinger, Zeitschrift für org. Physiol. t. ii. p. 446.

local phases of development occur in this period; for example, in the human subject the first irruption of the teeth, beginning about the middle of the first year after birth, and the displacement of the temporary teeth by the permanent set, which commences in the sixth year. The changes of development afford a basis for the establishment of a period of childhood, extending to the sixth year; and a period of boyhood, reaching to the fourteenth or fifteenth year. In the former of these periods the necessity for nourishment is greatest, the changes of material which the organs suffer is more rapid and greater in degree, and the quality of the food is consequently now of the greatest importance. Hence, in childhood, the organs frequently become affected with various defects of material composition, or defects which are maintained by improper food being given. Such are the diseases called mollities ossium, scrofula. When the period of boyhood commences, the mind has acquired the capacity and strength required for the accumulation of knowledge and for its own cultivation; the process of growth now progresses less rapidly; and the organs of the body receive their permanent material composition. This is the age occupied by education and mental culture, when the foundation is laid in which all the future operations of the mind have their root.

3. *The period of maturity* begins at puberty and ends at the period when the generative power is lost, which in woman occurs about the forty-fifth or fiftieth year. The period of maturity may be subdivided into the ages of youth, and manhood or womanhood. While the changes of development more especially characterising puberty, and already described, take place, the organs of respiration and voice (as has been mentioned in the section on the voice) undergo a further development, and the external form of the different parts of the body is perfected; the features at this period frequently undergoing a very rapid change and taking that character which they afterwards retain throughout life. The previously boyish countenance now serves to express more violent passions; the leading influence of others ceases and is no longer tolerated; the tricks of the child are cast off, and the errors of the youth who has become independent, who trusts to his own experience and feels himself free, begin to manifest themselves. The corresponding changes take place earlier and more rapidly in the female organism, and hence the girl deserts the games still followed by boys of equal age, upon whom she looks down with contempt, though when they also have passed the period of puberty she is timid and bashful in their presence. In both sexes the imagination is now most active; this is the period when the mind is most under the influence of a poetical fancy, when it is devoid of envy, avarice, and jealousy, and is filled with open disinterested friendship. A boundless field of action and meditation is in prospect. The limits to his capabilities of which the serious, cold man becomes conscious, are yet unknown. Love is the centre of the most noble feelings. The vegetative development, as far as it regards the individual, is now complete, and the increase of the organic force is applied to the new products of the generative function. Those individuals in whom the formative and equalising power was at first unstable and the material composition of the organism defective,

already manifest an inability to resist the action of external stimuli, particularly when these are applied to such important organs as the lungs; for the lungs at this period, on account of the increased development which they are undergoing, possess an extraordinary degree of irritability. Hence when the system has undergone the changes of puberty, there frequently appears a predisposition to pulmonary disease, which had previously remained latent during the active growth and development of the different parts of the body, just as hectic frequently ceases during pregnancy.

While the body continues to grow, the epiphyses of the bones remain separated from the diaphyses by sutures; the elongation of the bones taking place at these points. When the individual has attained his full stature, the epiphyses become united to the diaphyses by ossification.

In the age of manhood the slim forms of youth frequently give place to greater bulkiness and obesity of figure, which manifests a failing influence of the formative power over the masses of the body. At this period of life also the mind has attained its maturity, has laid aside the exuberance of the feelings, and is conscious of efforts made, of endeavours miscarried, of the limits of its faculties and of the feeling of possession; life has become more tranquil; the views of the individuals are more clear and more serious; he still has his passions, but they are active in another direction, in the acquisition of possessions and in self-defence.

Within the age of manhood there is no predominant disposition to diseases of particular organs. Yet in advanced manhood the morbid changes by degrees manifest a preference for those organs which are chiefly engaged in impressing chemical changes on the matters submitted to their influence, for example in the large glandular viscera; and the weakened vegetative power is the less able to resist obnoxious agencies the more frequently they are excited. It is not the lungs which now suffer; after the excitement which they experience in youth those organs gradually regain a state of repose. The organs of the abdomen are now especially subject to the abnormal changes; whilst the effects of foregone disturbances of the nervous system are more perceptible and more enduring than in youth when the foundation for them possibly was laid. The age of manhood is moreover particularly prone to mental diseases owing to the intensity of the shocks to which the mind at this period of life is subject.

4. The last great period of life may be designated the *period of sterility*. It extends from the cessation of the fruitful exercise of the generative function to extreme old age. The form of the body now loses its plumpness and "turgor." The growth of the hair which began on the head, and, subsequently, in the periods of youth and manhood, extended to the face, ceases also first on the head and continues to extreme age only in the beard. In old age also there is manifested a tendency to the deposition of calcareous salts in the cartilages and coats of the blood-vessels. The teeth or their remains lose their firm attachment to the jaw-bones, and after they have fallen out, the alveoli disappear. Hence the jaw-bones in old age become shortened. In this period of life, when all the development is at an end, there is a more or less uniform diminution in the energy of the different vital functions, while the intensity of the propensities, inclinations, and sympathies, the acuteness of the senses, the liveliness of the fancy, and the spirit of self-defence and resistance fail. Very few individuals reach an age in which this diminution of the faculties leads imperceptibly to the close of

natural life. In most persons the foundation of premature
But even independently of this circumstance the organi
processes of development are completed, bears a stronge
artificial mechanism than does the primary form of bei
chanism of the body out of its own mass, and therefore
which it may suffer. In old age a slight disturbance pr
is capable of arresting the whole mechanism.*

CONCLUDING REMARKS ON THE VARIETIES OF

From this review of the process of develop
animal organism, we are brought back again t
the general forms to which the individuals belong
or genera; and thus the conclusion of the "Sp
nects itself with these considerations which were
legomena on General Physiology." The races
suffer modifications under the various condition
posed in their distribution over the surface of the
cations do not exceed the limits marked out by
they are perpetuated as types of "varieties" of t
cessive generations. It is to these phenomena
now be directed.

It is important in this inquiry to attach defi
"species" and "variety." The species is a livin
individual beings, which reappears in the prod
certain invariable characters and is constantly re
rative act of similar individuals. The latter cha
species from hybrid forms. It is not an exclusiv
form which we denominate species, that one for
tion is capable of productive union with anoth
racter is inadequate to mark the two individu
belonging to one species. For individuals bel
species of one genus are likewise in some insta
gating with each other, as in the cases of the
horse and ass, where mules or hybrids are produ
genus, represented by different species and ind
pable of fruitful union with individuals of speci
genus. But hybrids, the production of which is
the natural repugnance of the individuals of diffe
tive union, cannot propagate their distinguishing
tion. The sexual union of hybrids is generally
fruitful, as in the case of the union of a hybrid
one of the species which had co-operated to for
duct relapses into the type of one of the original
reproduction of the same form by the sexual
viduals is therefore an invariable and essentia
species.†

"Varieties" are forms represented by individu the definition of the species. The individuals constituting one variety are capable of fruitful union not only with each other but also with individuals belonging to other "varieties" of the same species. Individuals belonging to different genera are not capable of fruitful union; and individuals of different species can propagate with each other, but their products cannot reproduce their peculiar form by generation; varieties have both these faculties. The mixed race produced by the union of two races is capable of propagation by union with similar individuals; but the union of the mixed race with the original race which had concurred in its production yields an offspring which in successive generations approaches more and more nearly to the type of the unmixed races. These characters sufficiently distinguish the "variety" of a species, which, when permanent, is a "race." The variety may however be otherwise defined and distinguished from the species. The different species always remain distinct. The races composing them present no stages of transition of one species into another. Where different forms of animals exhibit this gradual transition of the one into the other, they cannot be regarded by the zoologist as distinct species. With the "variety" the case is otherwise. There is a remote possibility that the similar productive individuals of one variety of a species, or a race, inasmuch as they contain within themselves the essential properties of the species, might produce all the other varieties of the species, provided the internal and external conditions necessary thereto were in action during a long series of generations. But there is no remote possibility of one species being produced from another. All the phenomena at present observed in the animal kingdom seem to prove that the species were originally created distinct and independent of each other. While the different varieties of each species may be accounted for by supposing the original existence of a pair of individuals of opposite sexes belonging to the same species, and the constant action of different external modifying agencies, such as that of climate, upon several or many successive generations.

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* The subject of the different ages of man's life is treat
volume of Burdach's Physiologie.

† Consult on this subject Rudolphi, Beiträge zur Anth

The causes which give rise to the varieties of species are partly seated in the organisms of the animals themselves, and partly external conditions,—such as the food, the elevation above the sea, and the climate. Each species of plants and animals possesses within itself a power of variation within a certain limit, quite independently of any external influences. To this cause are to be referred the varieties of form which may present themselves in the offspring of one act of generation. In each individual of a species there is an innate capability of producing such varieties as these, since each individual of a species does not produce by generation the mere repetition of itself, but generates the new beings in accordance with laws which regulate the whole species. Thus from the same parents there may be produced individuals with fair and others with dark hair; some of spare and slender figure, and others of plump and stout robust form; individuals of different temperaments, and with different features, eyes, mouth, and nose, with hair

Natur-geschichte. Berlin, 1812. Prichard, Naturgeschichte des Menschen-geschlechts. Leipz. 1840, p. 174. Physical History of Man, London, translated into German by Rudolph Wagner; and also the notes of Wagner in the same work, p. 439.

in some instances curly, and in others straight. The most common varieties arising in this way from internal causes, are the fair and the dark haired. Fair persons are occasionally met with amongst races for the most part characterised by black hair,—for example, amongst the Mongolians: and Dr. Prichard adduces several examples of fair-complexioned negroes who were not albinos.

It is true that these varieties are chiefly due to the parents being individuals of different complexions, and to the characteristics sometimes of one and sometimes of the other being predominant in the offspring. But even when the parents have the same complexion, a certain variety of forms and internal properties may present itself in the offspring. In consequence of the mingling of these different varieties in marriage, their peculiarities are not preserved, and are not propagated as constant fixed types. It is easy to conceive the conditions which must be combined in order, independently of climate, food, and locality, to convert these accidental varieties into persistent types. The longer individuals of the same stock continue to unite in marriage, without foreign admixture, the longer will the type to which they belong be preserved. In this way, and independently of all external influences, a race will be formed. Sometimes when the type has become fixed through a series of generations in the members of a family, even the admixture of a foreign type is not sufficient to efface the fixed characters of the family, and the foreign element becomes lost in the older fixed type. Hence we see in many royal families that in spite of their union by marriage with other houses, the type of the family features is in a remarkable way preserved and transmitted from generation to generation,—as, for example, in the Bourbon family, and equally in many princely houses in Germany. It was previously shown how one family, being isolated by the intermarrying of its members exclusively with each other, might produce a nation or tribe with general distinguishing characters. History teaches us how the national type once formed is preserved in spite of individual variations through thousands of years, and that, except when modified by admixture with other types, it is maintained unchanged, as in the case of the Jews, even in the most varied climates which produce their peculiar modifications of form and complexion.

The propagation of like with like is, however, capable of perpetuating, not merely a physical type forming one of the varieties of a species, but also the faculty which individuals acquire by education. The peculiar properties of the hound, the shepherd's dog, and the watch-dog, for example, are all comprehended in the general notion of the species; and it is probable that in the brood of a single wild dog, or in the generations descended from this brood, through the inherent tendency of the species to the production of varieties, individuals occur which, when tamed, discover very different talents,—the one being more adapted for the chase, another for tending of sheep, and a third for keeping watch or guarding property. But the education and rearing of the dogs with the requisite endowments for the purposes mentioned, cause the faculties thus improved or acquired to be transmitted to succeeding generations, when this object is provided for by the pairing of males and females with similar endowments.

Varieties of species are also produced by external influences; and the longer the action of these causes is continued, the more constant does the particular variety become, and the more does it acquire the character of a type. To these external causes belong the climates or zones in which the animals live. The warmth or coldness of the climate has an especial influence on the fur or hairy coat of animals. Most animals, as is well known, have two kinds of hair in their coat,—namely, long and stiff hairs, and between these a shorter, curly, woolly hair. Now, the further a sheep is carried towards the north, the more equal does the proportion of the two kinds of hair in the coat become; while in sheep living in southern countries the woolly hair increases in quantity at the expense of the stiffer, longer hair. This is exemplified in the merino sheep inhabiting the mountains of Spain. Climate modifies also the "habitus" and size of animals. Cattle transported from the temperate zones of Europe,—for example, from Holland or England to the East Indies,—are said to become considerably smaller in their succeeding generations.* On the other hand, the skin of the cattle carried to South America has in a series of generations gradually become so much changed in its properties, that the Brazilian hides now supply the best leather. The guinea-pig, Cavia aperea, which in its native country is of a grey colour, since its introduction into Europe has become changed into a variety marked with brown, black, and white spots. The elevation of the locality above the sea also, independently of the degree of latitude, has an influence over the forms of animals. According to Sturm, the hog in low countries or districts,—as in East Friesland,—attains the greatest size of trunk, with long and deep flanks, but with short legs. While in proportion as the country the hog inhabits is elevated above the level of the sea, the smaller and more compressed becomes its body, the less tapering and shorter its head; the shorter and thicker its neck, and the more rounded its hind quarters. But the food also modifies the form and nutrition of animals; hence in the low countries of Holland, East Friesland, and Holstein, the cattle are remarkable for their large size, and for the abundant supply of milk which they yield, while they are defective in both these qualities in barren Iceland.

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* See Sturm, Uber Racen, Kreuzung, und Veredlung der landwirthschaftlichen Hausthiere. Elberfeld, 1825, p. 54.

The concurrence of different conditions of internal as well as external nature, which cannot be severally defined, has produced the existing races or fixed varieties of different species of animals; the most remarkable of which varieties are to be met with in those species which are susceptible of the most extended distribution over the surface of the earth.

The principal modifications, in addition to those of external form, are to be found in the skin, in the coat, the horns, and the adipose deposits. Sometimes the ears are lengthened and become pendulous,—as in the Kirghisic sheep, and some varieties of the dog; sometimes the horns are wanting,—as in the English sheep, or are spirally twisted,—as in the Hungarian sheep; sometimes the adipose tissue is accumulated in the form of a hump on the back,—as in the little zeburind, or in the tail,—as in the sheep of Thibet and the bucharei; sometimes the hair of the coat is curled, as in the poodle-dog, or forms a very thick wool, as in the merino sheep. In the human species also prolongations of the skin, varieties in its appendages, and local accumulations of fat occur in different races; for example, the elongation of the nymphæ and their commissures in the Hottentot females and the females of the Bosjesman or Bushman race; the straight hair which may be abundant or scanty, the curly hair and the woolly crisp hair, and the accumulation of fat about the buttocks and sacrum of the Hottentot and Bosjesman females.

The modifications in the form of the species produced by the influence of climate are seldom so deeply rooted, that they are not gradually lost when the climate is changed, and then they may be replaced by the peculiarities produced by the new climate. Thus the wool of merino sheep, imported by Englishmen into some of the South Sea Islands, has soon become changed into straight hair. The wool of the same variety of sheep, when they are transported to Peru and Chili, very soon gives place to straight stiff hair. (*Sturm*, op. cit. p. 42 and 50.) A German gardener repeatedly imported the seeds of the white cabbage from Germany into Naples in order to rear heads of cabbage which at the latter place were still unknown; but he always failed, for he could raise only leafy cabbage, or the cauliflower variety. According to Sturm also, the Siberian naked barley, Hordeum cæleste, when grown on the Rhine frequently degenerates into common barley.

There are, however, examples of typical varieties produced by influences connected with climate, which have not lost their peculiarities in successive generations when transplanted to a different climate, provided the preservation of the type has been favoured by the individuals of the variety constantly propagating with each other. The different races of mankind afford the most striking examples of this fact.

The races of the human species answer to the general notion of a "race;" they are different forms of one species which are capable of fruitful union, and are propagated by generation: they are not different species of one genus; for were that the case their hybrids would be unfruitful. Here, as in the case of other animals, all the varieties are to be regarded as aberrations from one type, caused partly by differences in the progeny of the same parents maintained by repeated propagation of similar forms with one another, and partly by the external influences connected with climate. Whether the first individuals of the species were originally placed in different parts of the globe at the same time, or whether they existed originally in one spot, and have spread themselves thence over other parts, is a question not affecting this statement. Some of the extreme forms of the races of mankind are certainly varieties which are no longer produced anew with all their distinguishing peculiarities, either by internal causes, or by the influences of climate, and which lose their characters in no climate, but propagate them in all their purity when foreign admixture is avoided. For negroes in the temperate and colder climates remain black, and retain all the characters of negroes, and also by generative union with each other produce only negroes; whilst Europeans in hot climates, except that the colour of their skin becomes somewhat darker, retain the characters of the European race. Under the same degrees of latitude negroes, Europeans, and the copper-coloured American Indians retain their respective forms and colours; and on many of the Australian islands there are found natives with all the characters of the Malay race, and with them black men of the negro variety. Yet even these races are not so absolutely distinct that the innate tendency to variation does not determine in one race individual cases of approximation to another, and that the same does not happen from the influences of climate. Individuals of the European race sometimes have hair nearly as crisp and woolly as that of negroes. The negro form of the face and head likewise occurs in individual cases amongst the Europeans. Weber states, that besides the ordinary oval form of the skull, there may be found amongst Europeans skulls of the elongated and quadrangular forms which are to be regarded as instances of sporadic approximation to the negro and mongolian types. The differences in the form of the pelvis in different races have been much elucidated by Vrolik. The form of the pelvis is sometimes very different from the ordinary European type, and particularly in the negroes and Bosjesmans, in whom the vertical position of the iliac and other characters indicate an approach to the form of this part of the skeleton in brutes. But in the form of the pelvis also the different races present aberrations from their proper type. According to Weber's researches there are in every race examples of pelves with the inlet of the oval, the round, the quadrilateral, and the wedge-like form. In the negro race there are many aberrations from the general type, such as the brown-black colour of the Hottentots and Bosjesmans, the only half-woolly hair of the Papuan negroes of Australia, the coalescence of the ossa nasi into one bone, which sometimes occurs among the Hottentots and Bosjesmans, and the elongated nymphæ of those tribes. Moreover, although the action of light and the temperature of different climates on the skin is extremely various in different races and nations, yet their influence is to a certain extent evident in all races; in all the skin is more or less darkened by residence in hot climates. This susceptibility to the action of light and heat is greatest in the negroes; so that the child, which during its embryonic existence was white, becomes coloured by exposure to the light after birth. In Europeans of fair complexion the skin does not become darkened from exposure to the light, which it does in Europeans with dark hair.

The question whether the different races of mankind all derive their origin from one parent stock or from several stocks, can never be determined by practical observation. But this question is not so important in reference to the theoretical explanation of the races, as some physiologists have supposed. For whether many or few individuals of an animal or plant were created at the same time, still the conditions which give rise to the varieties would exert their influence on individuals. The history of the races of animals and plants conducts us inevitably to the conclusion that all the true varieties of one species may be produced by the action of internal and external causes through a sufficiently long period of time on individuals of the species.

It is impossible to make a strict division and classification of the races of mankind. For the various forms do not possess equally marked peculiarities, and there is no such sure, scientific, intrinsic principle to guide us in defining their limits, as there is in the case of the species. The object of a physical history of man is to describe all the peculiarities of the nations which maintain themselves distinct by the successive generations of each not mingling with those of the others; but the contemplation of mankind in this extended manner does not come within the scope of this work. All that is here practicable is to enumerate the most conspicuous of the races of mankind according to the arrangement proposed by Blumenbach, which is still preferable to all others, because it is the most convenient.

The races distinguished by Blumenbach are:—

1. The *Caucasian race.*—In this race the colour of the skin is more or less white, passing into flesh colour; more rarely it is of a light brownish colour. The hair is more or less wavy, and of a light or dark tint. The forehead is high and arched; the face oval; the facial angle*

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* By the facial angle is understood the angle included between the facial line and a horizontal line drawn from the base of the cranium. The former of these lines touches the glabella or space between the eye-brows and the most prominent part of the superior maxilla beneath the nose; the latter line is the middle line of a plane passing through the anterior nasal spine of the superior maxilla and the meatus auditorius externus. This angle is always larger in children than in adults. In the same way it is proportionally large in young apes as in the young ourang, while in full grown apes it is much smaller, and the face has consequently a much more brutish character. The size of the facial angle is determined by the proportion borne by the cranial portion of the head to the parts occupied by the senses and those engaged in mastication and the taking of food. In the antique sculptures this angle is enlarged to the extent of a right angle, and still further, in order to give a more noble expression to the head, and hence in this point the form of the child is transferred to the adult. According to the researches of Tiedemann the capacity of the cerebral cavity of the cranium is the same in different races of men, how different soever the external

large, namely, from 80° to 85°. The nose is arched or prominent; the teeth perpendicular; thickness; the chin prominent; the beard abun of the growth of the hair of the surface genera menbach assigns the Europeans (with the excep and Finns) the inhabitants of Western Asia, Ganges, and the Caspian Sea, and also the Nort

2. The *Mongolian race.*—The characteristics o are a yellow complexion; black, straight, sca face, which is widest where the cheek bones p glabella (the space between the eye-brows); a tened nose; narrow and oblique openings of placed wide apart.

To this race Blumenbach refers all the Asiati Caucasian variety, except the Malays; the La Europe; the inhabitants of the most northern Esquimaux and Greenlanders.

3. The *American race* has a brownish coppe straight, scanty hair; a beard more or less fe more or less prominent. All the other characte are neither constant nor striking.

This race comprehends all the Americans not ing variety.

4. The *Ethiopian race.*—The characters are black complexion; black, generally coarse, sh hair; a narrow and long skull; a retiring forehe jaw with a retiring chin, and teeth projecti turned-up nose, compressed above; thick lips; only 70 to 75°.

All the inhabitants of Africa, except those bel variety, namely, the African negroes, and the n and the Indian Archipelago, or the Papuas, con

5. *The Malay race.*—The skin is black; the and abundant; the cranium moderately narro the upper jaw moderately prominent; the nose s thick, and the mouth wide.

To the Malay race belong the brown islande inhabitants of the Sunda Isles, the Moluccas, th anne Isles and the true Malays of Malacca.

It would, doubtless, be more consonant with races as constant and extreme forms of the va to endeavour to make them include all the nati which is impracticable and which science does formed. The attempt to effect such an arrange of mankind under one or other of these classe arbitrary classification. The position of the Ta in relation to the Mongolian and Caucasian and they cannot be referred to either exclusivel

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forms of the skulls may be. See Tiedemann, Das Hir Europäers und Orang-utans vergleichen. Heidelberg, 18 trary decision. The same remark applies to the Papuas and Alfouros in regard to their classification with the Malays or with the negroes. Amongst the islanders of the Pacific both black and brown and even white men may be distinguished; at all events, in the Society Isles there are white natives as well as those of a yellowish-brown complexion. In this case the whites cannot be referred to the Caucasian race, any more than the idea can be entertained of classing the Guyacus of America with the Caucasian race on account of their light complexion. On the contrary, these varieties seem to have arisen among these nations in the same way as the fair and dark complexioned varieties have been produced among Europeans. But it further admits of inquiry whether the Papuas and Alfouros should not be regarded as distinct from the African negroes in their origin, and whether these black races of the Indian Archipelago are not, on the contrary, much more nearly related to the brown Malay race, in which case these blacks and the brown Malays might be supposed to stand in the same relation to each other as the true negroes and the dark-brown inhabitants of Southern Africa. No necessity exists for deriving all the black people on the globe, or all the brown, or all the white races from the same root; on the contrary, since we have seen that varieties may arise among the progeny of one stock, it is easy to conceive how it is possible for nature to produce similar forms in nations which are far removed from each other, and, according to the records of history, have never mingled.

Similarity or difference of language may sometimes aid us in determining the relation borne by a particular people to the principal races of mankind, but even this criterion is not always trustworthy. For not unfrequently languages sprung from very different roots are met with amongst the people of one race. Languages, like races of men, perish, and are displaced by others.

With respect to the original roots of languages there may be distinguished upon the great continent of Europe and Asia:

1. The nations whose languages are derived from the Indo-European root; these languages are the Sanscrit, the Persic, the Greek, and Latin, the German Celtic, and the Sclavonic Celtic.

2. The nations speaking the Semitic tongues, namely, the Aramæic, Phœnician, Hebrew, Arabic, to which must be added the Aethiopic or Geezic in the Northern and North Eastern parts of Africa.

These are the nations of which the most perfect history has been preserved, and who have in the greatest degree been susceptible of civilisation. The same nations are comprehended under the name of the Caucasian race.

3. The nations using the Tschudic tongues, to which are referred the languages of the Hungarians, Finns, Laplanders, Samoyedes, Esthonians, Livonians, Permiens, Wogules, Ostiakes, Cheremisses, Mordwines, Koriakes, Tchuktches, and Kuriles, and, by some writers, the languages of the nations of the Caucasus, as the Georgians and the Circassians.

4. The nations speaking the Tartar or Mongolian tongues, as the Mantchoo in China, the Turkish, and the dialects of the Uzbecks, Bucharians, Bashkires, Yakutes, Kirghises, Calmucks, Tungooses, &c.

5. The nations having monosyllabic tongues, partly languages of

symbols, as those of China, Tonkin and Cochin
with syllabic alphabets, as those of Thibet, Si
languages have no inflections, and express the
means of intonation.

Australasia is inhabited partly by brown
brownish-black Papuas and Alfouros. The Al
parts of most of the Moluccas, and Philippin
and New Guinea, also in the North of New
New Ireland, Louisiade, Bouka, Santa Cruz,
are scattered through the interior of New Holla
as the original inhabitants. M. Lesson descrit
legs, prominent teeth, rough, thick, straight ha
dirty brown or black complexion. The Papu
variety and live on the coasts, call the Alf
Papuas, who live on the coasts of many isla
appear to be a mixed variety between the Mal
true Papuas, and resemble the inhabitants of M
is moderately woolly, thick, and long; their
dilated transversely, the forehead high, the bea
a deep black-brown.

The Malays have spread themselves from
sula of Malacca; and here also are found the
the mountainous districts, namely, beside the tr
tribes, woolly-haired Negritos.

Malay dialects, nearly allied to each other, a
pine and Sunda Isles and in Madagascar. Of
composed of similar words are the languages s
Tahiti, the Sandwich Islands and Tonga.

Africa is inhabited by two races. In the
Eastern parts dwell the Abyssinians, Nubians,
nations allied to the Indo-Europeans. All the r
by Negroes. The number of languages spok
same is the case in America, all the inhabita
except, perhaps, the (Mongolian) tribes of t
appear to be allied to each other, notwithsta
tinctions of Peruvians, Guaranians, Araucanian
cudos, Moluchas, Patagonians, Fuegians, Me
dians, and Californians.*

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* The works treating specially of the Natural Histor
De generis humani varietate nativa, Gott. ed. iii. 1795;
lectionis craniorum, Gott. 1790; P. Camper, Uber den
Gesichtszüge in Menschen verschiedenen Gegenden und
1792; Virey, Hist. Nat. du genre humain, Paris, 1824;
races humaines, Paris, 1826; Bory de St. Vincent, Der
Vrolik, Considérations sur la diversité des bassins de dif
sterd. 1826; J. M. Weber, Die Lehre von den Ur-und
Becken des Menschen, Düsseldorf, 1830; R. Wagner, Na
Kempten, 1831; Van der Hoeven, in Tijdschrift voor na
die Menschenracen in der Deutschen Vierteljahrs-sch
geschichte des Menschengeschlechts (Physical History
und Zusaetzen von R. Wagner, Leipz. 1840; Berthold,
Wörterb. d. Med. Wissensch. B. xxiii. p. 44. Mr. Lawre
Morton's Crania Americana, Philadelphia, 1839.

SECTION I.

CHAPTER II.[*]

The Allantois, Umbilical Vesicle and Umbilical Cord—Development of the Embryo in the Uterus.

Some additional particulars on Embryology will be given in this chapter.

The *allantois* in the chick is formed from the lower intestine, making its appearance on the third day as a pyriform vesicle, which grows rapidly, consisting originally of the mucous layer above, but receiving a covering from the vascular layer at a later period, and then presenting a thick network of blood-vessels, which consists of two umbilical arteries and an umbilical vein. Thus constituted the allantois shoots into the space between the amnion, and the serous investment, grows quickly around the embryo as a flattened bag or bladder, lying all the while close to the membrane of the shell, and coalescing by its two contingent surfaces, it finally forms a membrane that envelopes the ovum or embryo completely, and is now known by the name of chorion. (*Wagner*, *Elements of Physiology*, *Willis's Translation*, p. 196.)

The allantois is, according to Von Baer, composed of two layers, of which the internal one is a prolongation of the mucous membrane of the embryo, and the other, the external vascular layer in which the vasa umbilicalia ramify. In carnivorous animals this sac bears a close resemblance to the same part in birds; it extends entirely around the embryo, and invests the whole inner surface of the chorion, except at the part where the umbilical vesicle lies. That portion of the sac which lies in contact with the amnion, and which contains but few vessels, is the membrana media of earlier writers, and the "endochorion" of Dutrochet. The external portion of the sac, which is in relation with the chorion, is very vascular. The proper office of the allantois seems to be the conducting of the vessels of the embryo to the exterior envelope of the ovum, in which they ramify. So soon as the vessels of the allantois have reached the chorion, they send minute branches into the villi of that membrane. Thus are formed the roots which henceforth extend from the surface of the ovum into the parietes of the uterus, and from which the placenta is afterwards developed.

Both the chorion and the amnion, according to the researches of Breschet, Gluge, and Barry, are composed of nucleated cells.

The fluid of the allantois contains the secretion of the primordial kidneys or Wolffian bodies, and of the true kidneys. Allantoin exists in it; and in that of birds Jacobson has discovered uric acid.[†]

The umbilical vesicle.—It is now, says Wagner, (*op. cit.*) satisfactorily demonstrated, that the umbilical vesicle is constantly present as a normal formation in the earlier months of pregnancy, and that it is connected with the intestinal canal. Repeated observation has shown that the umbilical vesicle is relatively very large in the youngest embryos, that it rests immediately upon the intestine, and communicates with its cavity, having at this time a rounded or oval form. At a very early period, however, it becomes pedunculated; its neck is produced into a canal, which is hollow at first, so that its contents can be pressed backwards and forwards into the bowel. It does not remain long pervious; at the end of the first month it is already filiform—with the increase of the amnion, the umbilical vesicle is found as a pyriform body between this membrane and the chorion; it collapses more and more; the pedicle is obliterated in the second month, and becomes an extremely fine thread, which, however, may be traced to the end of the noose of intestine contained within the umbilical cord. Such continues to be the condition of the umbilical vesicle to the end of pregnancy, when it may still be demonstrated in the membranes; the shrunk vesicle itself may be discovered between the amnion and chorion, and its filiform appendage traced from it into the umbilical cord.

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[*] This chapter ought to have come in at page 848.

[†] The best figures of the ova of mammiferous animals will be found in the works of Von Baer and Coste, and in Gurlt's Anatom. Abbild. der Haus säugethiere. The authors to be consulted on the subject of the development of this class are, Oken and Kieser, Beiträge Zur vergleichende Anatomie and Physiologie, 1806. Dutrochet, in the Mém. du Mus. d'Hist. Nat. T. iii. p. 82. G. Cuvier, ibid. p. 98. Bojanus, Nov. Act. Nat. Cur. x. p. 1. C. Mayer, Ibid. xvii. 2. Coste, Recherches sur la Génération des Mammifères, Paris, 1834, et Embryogenie, Paris, 1837. Von Baer Entwickelungs-geschichte der Thiere 2te Thiel. Burdach, Physiologie, Bd. ii. Valentin, Entwickelungs-geschichte. R. Wagner, Physiologie and Icones Physiologicæ.

When the human embryo by means of its vessels has gained a vascular connection with the chorion, the allantois can no longer be discovered, the urachus of the urinary bladder,—a filament extending into the umbilical cord,—being its only remains.

The successive changes which the ovum undergoes may be referred to the following stages:—The first stage extends to the appearance of the embryo, elevating itself above the surface of the yolk-sac. The changes which occur during this period are the least known; but the villi of the chorion are at this time developed. This stage is illustrated by an observation of Mr. Wharton Jones.* The ovum which he describes had the size of a pea, and was stated to be aborted in the third or fourth week after impregnation, but may have become detached at a much earlier period. It lay imbedded in one side of the uterine decidua. One side of its external surface was smooth, the other beset with villi. The whole cavity of the chorion was filled with a gelatinous tissue, in which towards one end of the ovum a small round body,—the vesicular germinal membrane,—was imbedded. The embryo was not yet visible.

In the second period the embryo becomes separated by a constriction from the yolk-sac, and the amnion and allantois are developed; but the embryo is not yet attached to the chorion by means of the latter membrane. Two ova, observed by Dr. Allen Thomson, (*Edinburgh Med. and Surg. Journal*, No. 140, figs. 1 and 2,) belong to this period. Both these ova were beset with villi of the chorion. One measured one quarter of an inch, the other one-half of an inch in diameter. A third stage of development extends from the period of the attachment of the ovum to the choroid by means of the allantois, to the complete formation of the umbilical cord. The amnion, however, has not yet formed a sheath to the umbilical cord enclosing all the parts which issue from the abdomen of the embryo. This stage also is illustrated by an observation of Dr. Allen Thomson.

When the amnion and chorion have come into close relation with each other, the ovum undergoes very little further change, except that the villi of the chorion become accumulated at one spot in order to the formation of the "placenta," and that the vessels of the chorion extend at this spot only into those branched processes or villi with clubbed extremities which, like the rest of the membrane, are composed of nucleated cells. The villi, however, do not disappear from the other parts of the chorion, but merely the interspaces between them become greater in consequence of the growth of the entire ovum. Even in ova of the full period these villi are still found upon the chorion.

During the development of the embryo the umbilical cord undergoes a constant increase in length.

In the fully formed ovum the following membranes are found in passing from without inwards, closely applied to each other; first the decidua, next the chorion, and last the amnion; the amnion being reflected upon the inner surface of the chorion at the point of insertion of the umbilical cord, of which it forms the sheath, while at the umbilicus it becomes continuous with the integument of the embryo. The cord invested by this tubular sheath of the amnion, contains the following parts:

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* Philos. Transact. 1837, p. 339. See also an account of an early ovum observed by Volkmann in Müller's Archiv. 1839, p. 248.

1. The remains of the ductus omphalo-entericus, or pedicle of the umbilical vesicle; accompanied by
2. The vasa omphalo-meseraica, branches of the mesenteric vessels of the fœtus;
3. The urachus; and,
4. The vasa umbilicali, which in the latter period of uterine gestation constitute the principal part of the umbilical cord. In mammiferous animals there are generally two umbilical veins as well as two arteries; but in the human subject there is but one umbilical vein and two umbilical arteries. The umbilical arteries are the main branches of the arteriæ hypogastricæ. They convey the blood of the fœtus into the placenta, or rather into the vessels of the aggregated villi of the chorion, which form the greater part of the placenta. In these villi which are imbedded in the decidua of the uterus or the uterine placenta, the blood of the umbilical arteries passes through loop-shaped capillaries into small veins, which by their union form the vena umbilicalis. The vena umbilicalis, of which the persistent vena abdominalis of reptiles and amphibia is the analogue, pours its blood partly into the vena portæ and partly through the ductus venosus Arantii into the vena cava.

The *liquor amnii* of the human ovum contains, according to the analysis of C. Vogt, (*Müller's Archiv.* 1837, p. 69,) an alcoholic extract with lactate of soda, chloride of sodium, albumen, and sulphate and phosphate of lime. The liquor amnii of an ovum of 3½ months' gestation had a specific gravity of 1.0182; that of an ovum of 6 months, a specific gravity of 1.0092. In the former 1000 parts contained 10.77 parts of albumen; in the latter only 6.67 parts.*

Development of the embryo.—The process of development of the embryo itself may be briefly described as follows: *At the commencement of the second month* the length of the embryo extends to a few lines, or half an inch. The extremities are then visible in the form of leaf-like appendages, and the cavity of the mouth exists and is wide open; the anus is developed somewhat later; the coccyx is very prominent. The branchial clefts have not yet disappeared, though they soon afterwards become closed; the head acquires a considerable size; the eyes, which are at first placed laterally, assume a more anterior position, and the nasal cavities soon become developed. The attachment of the umbilical cord is yet very near to the posterior extremity of the trunk; but in the progress of development it moves more forwards, and at length occupies the middle point of the abdomen. *During the second month* the sheath of the umbilical cord is formed; the intestine, at first a straight canal, receives an angular bend with the apex of which the umbilical vesicle is connected, and this bent or loop-like part of the intestine is at this period received into the commencement of the vagina funiculi umbilicalis. *Towards the end of the second month* ossification also commences at several points, and the rudiments of the muscular system are formed. The heart is covered in, and the septum begins to be developed; the aortic arches are reduced in number to two, which unite posteriorly to form the aorta descendens, and one of which subsequently becomes the pulmonary artery. The glandular viscera, the lungs, liver, and the Wolffian bodies exist. The formation of the last named organs is soon followed by the development of the rudimentary kidneys, and the testes or ovaries. The external organs of generation make their appearance in the form of a wart-like prominence in front of the cleft which leads to the sinus urogenitalis. The urinary bladder is formed at a later period by a part of the sinus just named, leading in the direction of the urachus, being separated from the rest by a constriction. At this time the oral and nasal cavities are not separated; the eyelids and external ear, however, are beginning to be formed; the different parts of the extremities become perceptible, and the hands and feet present marks of the division into the digits. The embryo is now about one inch in length. *In the course of the third month* the fœtus acquires the length of two and a half or three inches; *in the fourth*, during which the sex becomes distinguishable, it reaches to four inches; and *in the fifth* to twelve inches. At this period occur the formation of the fat, and the further development of the rudimentary horny structures, the nails and the down, lanugo, which appears over the whole surface, and the eyelids coalesce. In the fifth month, also, the movements of the embryo are felt by the mother. A fœtus born during the *sixth month* breathes, but does not continue to live. In the *seventh lunar month* the embryo acquires the length of 16 inches or more, and if expelled from the uterus is sometimes capable of living; its skin is red. In the *eighth lunar month* its length is 16½ inches; the testes at this period descend from the abdominal cavity through the inguinal ring into the scrotum, which had hitherto the form of empty folds of skin, and the eyelids become free. In the *ninth month* the hair appears on the head, and the embryo measures 17 inches in length. In the *tenth lunar month* its length reaches 18 or 20 inches. At this period, or even during the eighth or ninth month, the membrana pupillaris disappears; and the skin, no longer so red, is covered by an unctuous matter, the "vernix caseosa," which, according to R. Wagner, consists of the desquamated scales of epidermis. In other animals the skin seems to throw off the epidermis in the form of a continuous membrane, and hence the body of the embryo has been frequently seen enveloped in this free epidermal membrane, whilst the hairs which had been formed subsequently were growing beneath it.

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* For representations of ova belonging to the different periods of utero-gestation I refer to the works of Soemmering, Leiler, Velpeau, and R. Wagner.

The writings which treat on the same subject are those of Kieser, Pockels, Burdach, Leiler, Velpeau, Bischoff, Valentin, Mayer, Coste, Von Baer, Wagner and Thomson, which have been already referred to; also Wrisberg's Descriptio Anatom. Embryonis, Gött. 1764; Autenreith's Suppl. ad Hist. Embryon. Hum. Tub. 1797, and the paper by the author in Meckel's Archiv. 1830, p. 411.

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